सत्यमेव जयते

Government of Rajasthan

Chief Minister's Rajasthan Economic Transformation Advisory Council (CMRETAC)

DEPARTMENT OF PLANNING, RAJASTHAN

POLICY STUDY ON ENERGY TRANSITION ROADMAP 2030

CEEW
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Technical Support Organisation
CMRETAC

2023

सत्यमेव जयते

Chief Minister, Rajasthan
& Chairman, Economic
Transformation Advisory Council

CHAIRMAN'S MESSAGE

Every state is important in the scheme of national development. We cannot assure the progress of India without the progress of the states. The Constitution binds us in a federal polity where every order of the government (Union, State and Local) has an important role to play. State governments are certainly closer to the people and hence bear an enormous responsibility towards ensuring effective delivery of goods and services.

In this endeavor, they have a direct, indirect, and enabling role to play. Rajasthan is committed towards that goal and has been at the forefront of many reforms since long. Our sincere and unceasing efforts, during the pandemic and otherwise, have been recognized widely.

The Bhilwara COVID-19 containment model has been recognized as a replicable model globally. Ours was also one of the first states in India which came up with a comprehensive strategy for economic revival in the wake of the pandemic. Besides taking a plethora of immediate steps to extend social and economic relief to the people during COVID-19, Rajasthan has also introduced several transformative measures in the recent past to boost the economy of the state. MSME Facilitation Act, 2019; Food Processing Policy, 2019; Tourism Policy, 2020; Mukyamantri Chiranjeevi Swasthya Bima Yojana, 2021; Handicraft Policy, 2022; Rajasthan Investment Promotion Scheme, 2022; Rajasthan Right to Health Care Act, 2022; Indira Gandhi Urban Employment Guarantee Scheme, 2022 and Vision 2030 are some of the path breaking initiatives undertaken by the government.

We also started a practice of 'thematic' annual budgets for converging our efforts and energy on most pressing issues and have ensured that governance is truly decentralized. Our campaigns on 'Prashasan Shehron Ke Sang Abhiyan' and 'Prashasan Gaon Ke Sang Abhiyan' are examples of that spirit.

While our efforts are incessant, structural slowdown and unexpected shocks like the pandemic can derail the economy. This calls for continuous preparedness on our part.

Creation of Chief Minister's Rajasthan Economic Transformation Advisory Council (CMRETAC) was a significant step to ensure our preparedness for short-term and long-term development objectives. In the year 2021-22, the Council prepared nine (09) policy studies on areas as diverse as Fiscal Management; Managing Urban Informal Sector; Integrated Agro-Business Infrastructure; Sustainable Agriculture; Doing Business; Quantifying Intangible Cultural Assets; Education and the New Paradigm (bridging digital divide); Medical Services; and Public Private Partnership in Infrastructure.

In the year 2022-23, the Council undertook six (06) new policy studies. These pertain to Building Energy Transition Roadmap; Financing Green Infrastructure; Urbanization of Rural Areas; Recalibrating Institutions to meet Climate Challenges; Using Data for Better Policy Formulation and Evidence-based Decision Making; and Redesigning Trade in the Era of E-commerce.

These policy areas may appear to be separate and discreet but one commonality that binds them all is that they are truly geared towards a bottom-up approach to the development of the state while embracing and addressing new challenges. I urge my colleagues in the state government to also focus on inter-linkages in these policy areas for the best possible outcomes.

I am confident that these fifteen (15) path breaking studies would be a valuable input for the state and I am happy to state that the present policy study is very much part of this endeavour.

I am grateful to the Members of the Council, my Ministerial colleagues, officers of the Government, all collaborators and organizations who have worked tirelessly to make this possible. My special acknowledgement of Dr. Arvind Mayaram, Vice Chairman, CMRETAC, whose leadership and contribution towards this endeavor have been extremely valuable. My appreciation is also to the entire team at CMRETAC which has diligently worked to put these reform-oriented studies together.

(Ashok Gehlot)

सत्यमेव जयते

Economic Advisor to CM
& Vice Chairman
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VICE CHAIRMAN'S MESSAGE

Realization of India's ambitious clean energy goals hinges on a transformative transition that must unfold within the individual states, each playing a crucial role in the country's sustainable energy future. India's aspirations for 2030 encompass two crucial targets: attaining 50% of its power generation capacity from non-fossil energy sources and reducing its emissions intensity of GDP by 45% compared to 2005 levels.

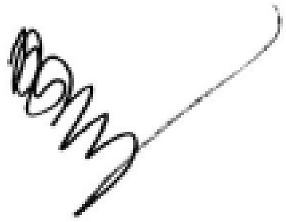
Rajasthan occupies a pivotal role in achieving these objectives. The state has achieved notable milestones, including universal electrification of households and villages, and becoming the country's leading renewable energy producer. The state is expected to have renewable generation capacity of more than 90 GW by 2030.

However, the pace of this transition is likely to be fraught with challenges that require immediate attention through strategic planning and execution of a short, medium and long term transition roadmap.

Addressing factors such as cost-effective integration of new renewable capacities, grid infrastructure enhancement, regulatory process streamlining and procurement cost optimization can accelerate progress towards Rajasthan's ambitious renewable energy objectives. Swift action to overcome these challenges will be essential for the successful realization of Rajasthan's clean energy ambitions.

With this objective, the Chief Minister's Rajasthan Economic Transformation Advisory Council (CMRETAC) in collaboration with the Council on Energy, Environment and Water (CEEW) developed an Energy Transition Roadmap 2030 for the state's power sector. This roadmap offers a comprehensive analysis of Rajasthan's power sector, delving into its RE ambitions, investment requirements, and strategies to meet 2030 targets. It explores seamless integration of RE capacity, system flexibility enhancement, efficient operation of the coal fleet, and measures to improve the financial health of the state Discoms.

I express my sincere thanks to Hon'ble Chief Minister for providing continuous support. I also express my gratitude to Hon'ble concerned Ministers, esteemed members of CMRETAC for their valuable guidance, concerned secretaries, other officers in the government, Technical Support Organization to CMRETAC and all other collaborators.



(Dr. Arvind Mayaram)

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Shalu Agrawal and Disha Agarwal co-conceptualised the study design, supervised the study execution including data collection, analysis, consultations, and drafting, and edited the entire manuscript. Prateek Aggarwal led the stakeholder coordination and data collection and co-authored chapters 2, 4, and 5. Dhruvak Aggarwal co-authored the executive summary and chapters 4 and 6 and led the execution of the peer-review process. Arushi Relan, Harsha V. Rao contributed to data collection, analysis, and co-authored chapter 3. Rashi Singh and Himanshu Anand contributed to data collection, analysis, and drafting of chapter 4. Bharat Sharma, Chanmeet Singh Syal, and Tarun Mehta contributed to the data collection, analysis, and drafting of Chapter 5. Pallavi Das, Zaid Ahsan Khan, and Vaibhav Chaturvedi performed the long-term modelling exercise and contributed to Chapter 2. Karthik Ganesan guided the execution of system modelling exercises and provided inputs at all stages.

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Finally, any error or omission that may have remained is solely ours and should not be ascribed to any of the above acknowledged person or institution.

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LIST OF ABBREVIATIONS

APPC	-	Average Power Procurement Cost
ARR	-	Annual Revenue Requirement
AT&C	-	Aggregate Technical and Commercial Losses
BESS	-	Battery Energy Storage System
BU	-	Billion Unit
CEA	-	Central Electricity Authority
CERC	-	Central Electricity Regulatory Commission
CUF	-	Capacity Utilisation Factor
DC	-	Declared Capacity
DRE	-	Decentralised Renewable Energy
EAC	-	Energy Assessment Committee
ECR	-	Energy Charge Rate
EPS	-	Electric Power Survey
FSA	-	Fuel Surcharge Adjustment
GCAM	-	Global Change Assessment Model
GoR	-	Government of Rajasthan
INR	-	Indian National Rupee
MBED	-	Market-Based Economic Dispatch
MoD	-	Merit Order Despatch
MoP	-	Ministry of Power
MTL	-	Minimum Technical Load
MU	-	Million Unit
NRLDC	-	Northern Region Load Dispatch Centre
O&M	-	Operation and Maintenance
PPA	-	Power Purchase Agreement
PSH	-	Pumped Storage Hydropower
RE	-	Renewable Energy
RERC	-	Rajasthan Electricity Regulatory Commission
RPO	-	Renewable Purchase Obligation
RRECL	-	Rajasthan Renewable Energy Corporation Limited
RRVUN	-	Rajasthan Rajya Vidyut Utpadan Nigam
RSD	-	Reserve Shut Down

RUVNL	-	Rajasthan Urja Vikas Nigam Limited
RVPN	-	Rajasthan Vidyut Prasaran Nigam
SCED	-	Security Constrained Economic Dispatch
SHP	-	Small Hydro Project
SLDC	-	State Load Despatch Centre
TPP	-	Thermal Power Plant
UDAY	-	Ujwal Discom Assurance Yojana
VC	-	Variable Cost/Charge
VRE	-	Variable Renewable Energy

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EXECUTIVE SUMMARY

The transition required to meet India's ambitious clean energy goals will play out in its states. By 2030, India aims to have 50 per cent of its installed power generation capacity based on non-fossil energy sources and reduce its emissions intensity of GDP by 45 per cent (over 2005 levels). Rajasthan, with abundant renewable energy (RE) resources, is positioned to lead India's energy transition to cleaner energy sources. The state is already the country's largest RE producer, with over 23 GW of installed RE capacity in June 2023 (Ministry of New & Renewable Energy (MNRE) 2023). The Government of Rajasthan (GoR) aims to achieve 37.5 GW of RE capacity by 2025 (MNRE 2022) and ~90 GW by 2030 in line with enhanced national clean energy targets.[1] However, an assessment of the state's past efforts and current context shows that several challenges may impact the pace of this transition.

A holistic approach is needed to determine future transition pathways for Rajasthan's power sector such that the transition aligns with the state's development aspirations, the nation's international commitments, and the changing global context. Understanding the long-term pathways should inform the state's medium-term policy goals, guiding the state's near-term strategies for sectoral transition. **Against this backdrop, the Chief Minister's Rajasthan Economic Transformation Advisory Council (CMRETAC) commissioned CEEW to develop an Energy Transition Roadmap 2030 for the state's power sector.** This roadmap, developed by CEEW with support and guidance from CMRETAC, is based on an in-depth analysis of the state's power sector landscape, emerging and potential challenges, suitable modelling tools and secondary research to answer the following key questions.

How can Rajasthan align itself with the national clean energy targets in the medium-long term?

- How ambitious can the state be in setting the 2030 RE goals?
- How much investment would it need to mobilise to meet 2030 goals?

How can Rajasthan pursue cost-effective integration of new RE capacities?

- What are likely to be the flexibility needs of the state's power system by 2030?
- What measures can help enhance the system's flexibility?

How can Rajasthan operate its thermal fleet in a cost-effective manner?

- How would the rising share of RE influence the state's power procurement costs?
- What measures can help optmise these costs in the short-medium term?

How can the state discoms become energy transition enablers, while delivering affordable and reliable supply to its people?

- What measures can help improve the financial health of state discoms

[1] Indicative target as per stakeholder engagements and secondary literature (Economic Times 2022; 2023).

The underlying research and roadmap development has benefitted from multiple rounds of consultations with key actors in the state's power sector. We hope this Roadmap assists and informs the Government of Rajasthan in leveraging its natural advantage of high RE potential to assume the pole position in India's clean energy transition and ensure universal access to clean, reliable and affordable energy for its people.

A. Aligning state ambitions with national clean energy targets

Our assessment of long-term transition pathways for Rajasthan suggests that aligning with the national aspirations of building a Net-Zero economy by 2070 would help the state retain its clean energy leadership while meeting its development aspirations.

Pursuing a Net-Zero pathway would present significant opportunities for the development of the state's power sector compared to a business-as-usual scenario, as depicted by the model results below.[2]

- The state's electricity demand would nearly double by 2030 and rise tenfold by 2070 due to a growing economy, rising incomes, urbanisation and a rapid electrification of various end-uses.
- Power generation within the state periphery would rise even faster to cater to clean electricity demand from within and outside the state.
  - Generation is expected to triple by 2030 and grow 16-fold by 2070.
  - Renewable energy will become a dominant generation source well before 2030 and contribute to ~60-70 per cent of generation (equivalent to 80-90 GW capacity[3]).
- The power sector would present the biggest opportunity for emission mitigation, given its majority contribution to the state's emissions (54 per cent share in 2020). If the power sector emissions peak around 2040,[4] they would need to drop to zero by 2050 for the state to align with India's net zero target. We also find that the power sector would need to decarbonise the fastest among all other sectors in this transition pathway.
- Investments of the order of ~INR 5.4 lakh crore (~USD 66 billion)[5] would flow into the state for setting up required generation (70 per cent), transmission (20 per cent) and storage (10 per cent) capacities by 2030.[6]

2 This analysis uses a state-level version of the Global Change Analysis Model (GCAM). Refer to Chapter 2 for more details.
3 As per draft Urja Niti 2050, the state aims to achieve 90 GW RE by 2030. It also highlights the massive RE potential and availability of abundant wastelands that favour rapid scale-up of RE in the state.
4 2040 is considered as the peaking year for overall energy sector emissions in the GCAM model as also in Chaturvedi and Malyan (2021).
5 Assuming USD 1 = INR 82
6 Chapter 2 provides details on the investments break-up across sub-sectors and/or generation technologies and the ways to attract these investments.

To realise these opportunities, Rajasthan should consider enhancing its clean energy ambitions by:

- Formally aligning with the national aspirations to build a Net Zero economy by 2070,
- Setting enhanced clean energy goals for 2030 in the form of 80-90 GW of RE capacity by updating existing policies, with a parallel emphasis on decentralised renewable energy, and
- Creating an attractive ecosystem to mobilise adequate investments for its clean energy goals.

B. Cost-effective integration of renewable energy

A rise in the share of variable RE (VRE) in Rajasthan's generation mix would pose several challenges linked to variability and uncertainty in RE generation, surplus availability during low demand (leading to negative net load) and limited inertia or reactive power support available for secure grid operations. Given these challenges, we assessed the need and the role of various generation sources and flexible options for optimal system dispatch at the state and national levels. In doing so, we undertook two distinct power system simulation exercises. One, an all-India dispatch modelling through which we assessed the role of Rajasthan in meeting the national flexibility requirement (referred to as case 1).[7] Two, a state-level dispatch modelling to assess the requirement of Rajasthan Discoms for achieving the RPO targets while also meeting the state's electricity demand (referred to as case 2).[8] A detailed exposition of these exercises is covered in Chapter 3.

To become India's clean electricity powerhouse by 2030, Rajasthan will need to enhance the flexibility of its power system.

Our assessment of all-India dispatch model (case 1) results suggests that:

- The share of VRE in the state's generation mix could rise to 72 per cent by 2030 (Figure ES1), which will be significantly higher than the share of VRE in the nation's power mix (33 per cent). This reconfirms that Rajasthan is expected to emerge as the clean power supplier to the nation.
- Storage and flexible generation resources will be key in meeting the peak demand and reducing RE curtailment. At the national level, to limit the annual RE curtailment within 5 per cent, the power system would need 44 GW of battery energy storage systems (BESS), 81 GW of thermal capacity retrofitted

7 National-level economic dispatch for each state modelled as a node using GE MAPS (GE Energy Consulting n.d.), including inter-state and regional transmission limits as a constraint to evaluate the cost-effective integration of 500 GW non-fossil capacity in India.

8 State-level copper-plate economic dispatch model using GridPath (Blue Marble Analytics n.d.) to meet state's demand and the renewable purchase obligation (RPO) targets for 2030.

to operate at 40 per cent minimum technical loading (MTL), and 22 GW of pumped storage hydropower (PSH). Despite this, 12 per cent of RE generation would be curtailed at the Rajasthan periphery (due to demand and transmission constraints)

- Of the total BESS capacity required, a majority (~32 GW) will be located within Rajasthan at utilisation levels that are attractive for investors. This indicates that Rajasthan will also be a major contributor to meeting the national flexibility needs.

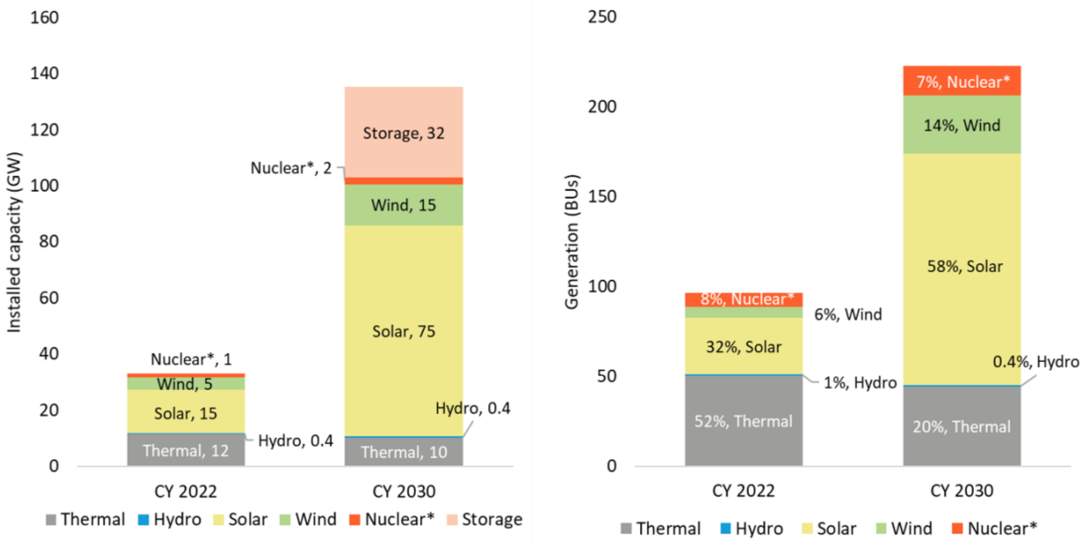

Figure ES1: With 90 GW of RE in Rajasthan, VRE share in generation would rise to 72 per cent

Source: Authors' analysis of inputs and outputs of the all-India dispatch model (case 1)

Note: (1) 'Thermal' includes coal and gas-based plants, and 'Nuclear*' predominantly includes nuclear, along with bio-energy and small hydro projects (SHP).

(2) The base year is considered as the calendar year (CY) 2022.

Rajasthan Discoms will need robust resource adequacy planning to meet the rising electricity demand.

Under the second modelling exercise (case 2), we examine the requirements of the load-serving entities (i.e., the Discoms) in Rajasthan to meet their renewable purchase obligation (RPO) targets. Here, we consider that the state balances the demand and generation on its own. Our assessment suggests that:

- The share of VRE in the contracted generation mix will increase from 17 per cent in 2022 to 39 per cent in 2030. In parallel, the share of thermal generation will drop from 74 per cent to 51 per cent. However, the annual utilisation of thermal capacity will increase to ~65, up from 58 per cent in 2022, to meet the rising electricity demand.
- But even with current and planned conventional generation capacities, seven per cent of demand remains unmet in 2030, mostly during non-solar hours and due to limited flexibility in the system (Figure ES2).

- Rajasthan’s 15-minute net load ramping requirement increases by 4-fold by 2030. The state must reduce select thermal units' minimum technical load (MTL), operate the existing coal fleet at part load, and ramp it rapidly. However, even if planned generation capacities become operational and CEA’s current standards for flexibilisation of thermal power plants are met, the system will not be flexible enough.

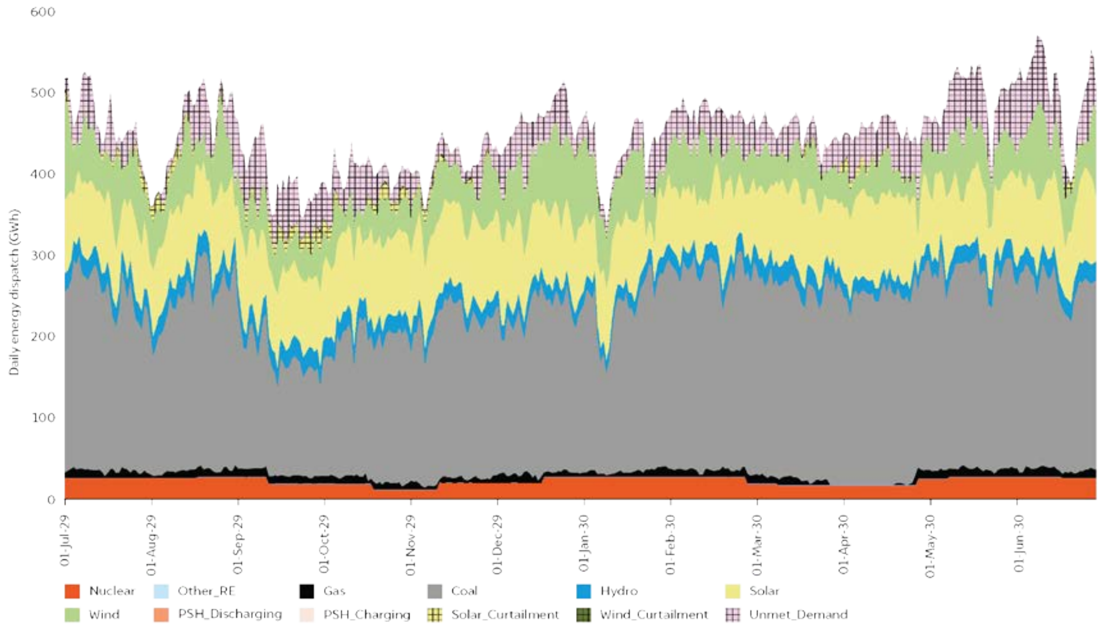

Figure ES2: With current and planned conventional generation capacities, 7 per cent of Rajasthan’s power demand would be unmet in 2030, indicating the need for more resources

Source: Authors’ analysis based on dispatch results obtained from case 2

Note: ‘Other_RE’ includes Bio-Energy and small hydro projects (SHP)

Flexibility can be enhanced to manage load reliably in a RE-rich power system by:

- Utilising RE with storage (BESS and PSH), the short-term market, and demand-side management,
- Upgrading the intra-state transmission network to ensure better system controls and enhanced communication abilities, and
- Implementing integrated resource planning to achieve a technically and economically sound resource mix in a planned and systematic manner.

C. Cost-effective operation of the coal fleet

To ensure that the system runs at least cost, flexible operation of coal-based generating sources will have to be managed cost-efficiently. Six state-owned and two privately-owned thermal power plants comprise nearly 40 per cent of Rajasthan’s total long-term contracted generation capacity and half of the annual energy procurement.

Our assessment of current operational trends suggests that:

- The annual declared capacity (DC) of state-owned plants was 32-68 per cent in the fiscal year 2022 (FY22), much below the annual target availability of 83 per cent, primarily due to technical issues. On average, nearly half of all thermal generating capacity in outage per day in the second half of the fiscal year was due to technical issues.
- While the 'merit order dispatch' (MoD) principle was largely followed for scheduling thermal power plants, Discoms would have saved nearly INR 500 crore in FY22 if eight of the largest coal plants had met their target availability and were utilised cost optimally.
- Historically, Rajasthan has witnessed significant deviations in the projected and actual annual peak demand and consumer segment-wise energy requirement, critical power system operation and planning inputs. The accuracy of forecasts on operational timescales of week- and day-ahead is 80-90 per cent, which can be improved.

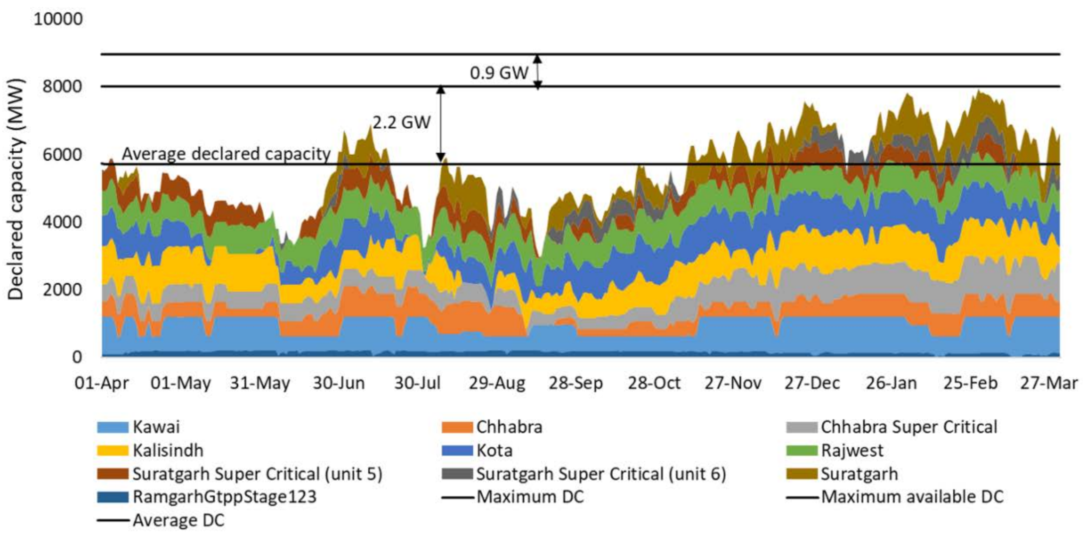

Figure ES3: Higher declared capacity of the largest state thermal plants could improve peak generation availability by almost 1 GW

Source: Authors' analysis using data from Rajasthan SLDC for FY22

Note: The maximum possible declared capacity is the cumulative plant wise installed capacity minus auxiliary consumption.

State entities can ensure that the coal fleet continues to operate cost-efficiently by:

- Increasing the utilisation of allowed O&M expenses to reduce the incidence of technical outages, revising regulations on normative O&M expenses, and facilitating timely payments for energy,
- Notifying a methodology for estimating the variable costs of plants and drawing up the MoD stack, and
- Using advanced metering infrastructure to collect and store granular load data and using advanced statistical tools for high-accuracy demand forecasts.

D. Towards a financially robust power distribution sector in Rajasthan

Rajasthan's Discoms are in financial distress with aggregate technical and commercial (AT&C) losses of 17.5 per cent in FY22, accumulated losses of ~INR 90,000 crore (including regulatory assets worth ~INR 49,000 crore), total debt worth ~INR 66,000 crore, and a low debt-to-service-coverage ratio of 0.91. State Discoms are in a vicious cycle of recurring losses, debt, delayed payment to generation companies, poor credit ratings, and high-interest burden. Since Discoms are the largest off-takers of clean energy, a perception of high off-taker risk is a key barrier to clean energy investments in the state.

Our assessment of the factors leading to loss accumulation suggests that disallowed costs by the state regulator during the true-up process are a major contributor to the accumulated losses of Rajasthan Discoms. In FY22, RERC disallowed over INR 6,000 crore of the Discoms' claimed expense, 59 per cent of which pertained to power purchases owing to gaps in forecasting and Discoms' operational inefficiencies. Disallowed costs reflect as losses in the Discoms balance sheet, affect cash flows, and add debt and interest costs.

Rajasthan Discoms must undertake measures to break out of the vicious circle and to:

- **Boost their credit ratings** to enable access to debt at attractive rates and check the rising interest cost burden.
  - In the short term, Discoms and the state regulator must pursue timely subsidy (as done in FY22) and revenue realisation, timely tariff filing, and release of tariff orders.
  - In the medium term, efforts must focus on timely payments to the generating companies and reducing the ACS-ARR gap through optimizing power procurement projections, improving billing efficiency and dissipating built-up regulatory assets.
- **Improve their billing efficiency** to reduce distribution losses and lower the extent of disallowed costs and revenue gap. In FY22, Rajasthan Discoms reported 100 per cent collection efficiency, but their billing efficiency was 82.51 per cent. State Discoms must leverage the opportunity to improve their billing efficiency through smart meter deployment and focus on:
  - Effective consumer engagement and awareness strategy
  - Designing and developing system architecture for secure and integrated data storage, sharing and management system
  - Enhancing institutional capacity by creating well-staffed smart meter units, conducting periodic training on smart meter technology

- **Implement a dissipation schedule for the unfunded revenue gap,** which largely forms the accumulated losses. Between FY11 and FY23, cumulative carrying costs of ~INR 49,300 crore have been allowed on the accumulated unfunded revenue gap, which has resulted in an interest cost burden on consumers equivalent to 8-10 per cent (INR 0.58/kWh) of the average electricity tariff. If the status quo remains, we estimate that the consumers would be levied with a carrying cost of ~ INR 52,000 crores over the next decade, with the unfunded revenue gap remaining unrecovered. Proposed solution:
    - Discoms can swap the existing expensive loans against the unfunded revenue gap with cheaper debt and reduce the carrying cost burden using the transitional finance route. Along with swapping of loans, a regulatory surcharge of ~5 per cent (per unit additional impact of INR 0.35/kWh) can ensure dissipation of the accumulated unfunded revenue gap in 5-8 years (5 years for AVVNL, 7 years for JVVNL, and 8 years for JdVVNL). The dissipation schedule would save consumers a carrying cost of INR ~17,300 crore in the near term.
    - Regulatory surcharge should be levied separately in the electricity bills for consumers. For Discoms, the surcharge should be reported separately in the billing database. A clear and separate accounting of the revenue gap and associated carrying costs will improve transparency and allow their time-bound recovery.

We propose a detailed Energy Transition Roadmap until 2030 for Rajasthan based on our assessment of system requirements and the various aspects of power sector operation. The Roadmap in Chapter 6 has been made after multiple rounds of stakeholder consultations and is based on the current understanding of technologies and institutional capacities. The proposed timelines may vary based on the pace of technological developments and the implementation momentum. We also propose a two-tier institutional framework that draws from the institutional arrangements under existing policies in the state, such as the Rajasthan Solar Energy Policy, 2019 (GoR 2019a) and the Rajasthan Wind and Hybrid Energy Policy, 2019 (GoR 2019b).

1. STRATEGIC CONTEXT

India's drive to fuel jobs, inclusive socio-economic growth and sustainable development, and its commitment to global climate action has led it to set ambitious clean energy targets. By 2030, India aims to have 50 per cent of its installed power generation capacity based on non-fossil energy sources and 45 per cent lower emissions intensity of GDP over 2005 levels (Government of India (GoI) 2022). By 2070, India targets to become a net-zero economy (ibid).

The transition required to meet these goals will play out in India's states. With its enormous renewable energy (RE) potential, Rajasthan can play a leading role in this transition. Rajasthan has already achieved two significant milestones: universal electrification of households (Ministry of Power (MoP), n.d.) and villages (Government of Rajasthan (GoR) 2023) and becoming the largest RE-producing state in the country with more than 23 GW of installed RE capacity (as of June 2023) (MNRE 2023).

Due to its generous endowment of RE sources, the state aims to achieve 37.5 GW of RE capacity by 2025 (MNRE 2022). However, an assessment of the state's past efforts and current context shows that several challenges may impact the pace of its clean energy transition. These include challenges of cost-effectively integrating variable RE (VRE) with the grid, barriers to the cost-optimal operation of existing resources, concerns around managing rising energy and peak demand, and the poor financial health of the power distribution companies (discoms). Addressing these in a timely and systematic manner would be crucial.

The state needs to revisit and align its clean energy ambitions with the enhanced national commitments. In doing so, it will be important to identify feasible pathways rooted in the current context and aligned with the state's aspirations for socio-economic growth.

1.1 Rajasthan's power sector at a glance and the current challenges

The state's power sector has continuously evolved with economic development and a growing consumer base. Between FY12 and FY22, the per capita electricity consumption in the state grew at a compounded annual growth rate of 3.79 per cent (Central Electricity Authority (CEA) n.d.). Rajasthan's electricity demand could continue to grow rapidly, albeit with higher uncertainties. The state's power demand could almost double by FY31, with peak demand estimated to rise by 75 per cent (CEA 2022a). Economic growth, rising incomes and urbanisation will continue to drive technology uptake and end-use electrification, driving power demand growth on the one hand but increasing uncertainty for supply-side planning. Figure 1.1 provides key highlights of Rajasthan's power sector.

Figure 1.1: Rajasthan's power sector at a glance

Growing electricity demand with economic growth

Peak Demand - 15.8 GW

Contracted Capacity
Thermal - 12.9
Solar - 4.3
Wind - 4.1
Hydro - 1.7
Others - 0.5

Total – 23.5 GW

(as of March 2022)

An expanding transmission and distribution infrastructure

Transmission ~ 45,864 ckt. km.
Distribution ~12 lakh ckt. km.
(as of March 2022)

Huge renewable energy potential

Average solar insolation of 5.2 to 5.7 KWh/sq. m/day across districts and abundant wasteland availability[1]

Coal-based power forms 69 per cent of the power procurement mix of ~91 billion units.

Thermal- 69%
Renewable Energy- 17%
Hydro- 7%
Nuclear- 3%
Others[$] - 4%

(for FY 22)

Agriculture and domestic demand comprises 63 per cent of the projected electricity demand of ~69 billion units.

Agriculture - 43%
Domestic - 20%
Industry - 27%
Commercial - 7%
Others* - 3%
(for FY 22)

Renewable Purchase Obligation (RPO) compliance

Target - 20.0%
Achievement - 13.5%
(as of March 2023)

Smart metering, the big initiative underway

Target -1.4 crore consumers by 2026

Actual – 6 lakh smart meters installed so far.

(as of July 2023)

Significant reduction in Aggregate Technical and Commercial (AT&C) losses

FY 20 - 29.4%
FY 23 - 15.5%

Leading renewable energy deployment in the country

16.5 GW grid-connected solar capacity (29% of India's total installed solar capacity – highest among states)

5.19 GW installed wind capacity (12% of India's installed wind capacity)

(as of July 2023)

Sources: CEA (2023a); National Smart Grid Mission (MoP n.d.); RERC (2023a); discoms' data obtained through the CMRETAC

Notes: *Includes public street lights, public water works, electric traction, EV, and mixed load.
[$]Includes power purchases from short-term sources.

[1] As per the Draft Rajasthan Energy Policy 2050.

Rajasthan has an important challenge at hand: How to decarbonise its electricity mix while meeting the rising demand through clean, reliable and affordable electricity services? At present, fossil fuels dominate Rajasthan's generation mix. Coal-powered generating stations met nearly 70 per cent of the state's electricity demand in 2022.[2] The GoR launched the Solar Energy Policy 2019 and Wind and Hybrid Energy Policy 2019 (GoR 2019a; 2019b) to create a supporting ecosystem for renewables in the state. Since then, the state's total installed solar and wind capacity has tripled from 7.8 GW in March 2019 (CEA 2019b) to more than 23 GW in June 2023 (MNRE 2023). However, the state's power distribution companies (discoms) have contracted only a fraction of this capacity (4.3 GW solar and 4.1 GW wind as of July 2022[3]). Thus, against the renewable purchase obligation (RPO) of 20 per cent, Rajasthan's discoms have met only 13.5 per cent in FY23.[4] By 2030, the discoms need to meet an RPO target of 43 per cent, implying a significant increase in the share of RE in the state's transmission and distribution network (MoP 2022). The higher RE share would pose new challenges for system planning, governance and operations. It will be crucial to assess the impact of increasing RE in the state's grid to determine cost-effective strategies for RE integration.

Poor financial health is a key factor constraining the discoms' progress in meeting their RPO targets. Over the past three years (FY20-22), the average aggregate technical and commercial losses of Rajasthan discoms stood at 24.5 per cent (Power Finance Corporation (PFC) 2021; 2022; 2023) (three times the world average). Discoms' poor financial health significantly restricts their ability to support and offtake more RE and provide quality and affordable services to its consumers. Addressing the root causes of the discoms' financial distress would be critical to making them transition-ready.

The financial challenges stemming from the distress in the electricity sector have significant ramifications for the finances of state governments. Rajasthan is among the few states which has not been able to meet the limits of fiscal targets (ratios of debt and gross deficit to gross domestic product of the state (SGDP)) set by the Finance Commission. However, if discom revenue gap and outstanding liabilities are added to the state finances, the situation indeed becomes alarming. The debt to SGDP ratio increases to almost 43.61 per cent and the deficit to SGDP ratio increases to 6.5 per cent from 40.36 per cent and 5.8 per cent respectively (PFC 2022; Reserve Bank of India 2023). Excluding subsidies and UDAY grants and including discom receivables inflates this figure even more (Anand et al. 2022). Consequently, addressing the financial health of discoms becomes an even more pressing imperative for the state government.

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[2] Based on daily implemented schedules provided by Rajasthan State Load Dispatch Centre (SLDC) and the Northern Regional Load Dispatch Centre (NRLDC).

[3] Data received from the Rajasthan Renewable Energy Corporation Limited (RRECL).

[4] Data received from RRECL.

The most substantial chunk of energy expenditure for the state government is directed towards subsidies. In FY22, these subsidies (INR 18,783 crore) accounted for more than 80 per cent of the total energy expenditure, while for FY23, they are estimated to surge to 88.6 per cent, reflecting a significant budgetary commitment. However, the state's fiscal deficit is already at a high level, leaving limited fiscal space to augment the allocation for the energy sector, which currently stands at approximately 9-10 per cent of the budget (PRS Legislative Research 2022; 2023). Given this constraint, it becomes imperative to explore alternative sources for financing capital subsidies and grants aimed at incentivizing projects like battery storage and other capital expenditures.

1.2 Roadmap objectives

A holistic approach is needed to determine future transition pathways for Rajasthan’s power sector to align with the state’s development aspirations and the nation’s international commitments. Such long-term pathways should inform the state’s medium-term policy goals, which, in turn, should guide the state’s near-term strategies for sectoral transition. **Following the above philosophy, this study outlines a roadmap (or plan of action) that could inform the government of Rajasthan in its efforts to leverage its natural advantage of high RE potential to assume a pole position in clean energy transition in the country.** The roadmap is developed based on an in-depth analysis of the state’s power sector context and emerging and potential challenges. It adopts a multi-step approach to answering the following key questions:

1. How can Rajasthan align itself with national clean energy targets in the medium-to-long term?
    - How ambitious can the state be in setting the 2030 RE goals? How much investment would it need to mobilise to meet 2030 goals?
2. How can Rajasthan pursue cost-effective integration of new RE capacities?
    - What are the likely state power system’s flexibility needs by 2030, and what measures can help enhance the system's flexibility?
3. How can Rajasthan cost-effectively operate its thermal fleet?
    - How would the rising share of RE influence the state's power procurement costs, and what measures can help optimise these costs in the short-medium term?
4. How can the state discoms become energy transition enablers while delivering affordable and reliable supply to its people?
    - What measures can help improve the financial health of state discoms?

Chapters 2-5 present our analysis of each of these questions. Chapter 6 summarises our key recommendations and presents the roadmap for Rajasthan’s power sector transition.

2. ALIGNING STATE AMBITIONS WITH NATIONAL CLEAN ENERGY TARGETS

Driven by a steadily rising population and a growing economy, the energy demand in Rajasthan will continue to grow rapidly in the coming decades. At the same time, the state's developmental aspirations and energy systems will be shaped by national and global advances and crises: declining costs of clean energy technologies, supply-chain disruptions due to geo-political stresses, changing investor preferences in response to climate change, and local environmental implications of fossil-fuel dependence. As India pursues the ambition of reaching Net-Zero (NZ) economy by 2070, it is pertinent to discuss:

- What could be a feasible long-term pathway to achieve economic growth while pursuing a net-zero future?
- What role can Rajasthan play in India's clean energy transition?

2.1 Modelling Rajasthan's long-term transition pathway

Using the state-level version of the Global Change Analysis Model (GCAM),[5] we assessed the implications of Rajasthan aligning with the national vision of net zero by 2070. We do so by modelling two energy-transition scenarios for all of India and deriving the results for Rajasthan:

1. Business-as-usual (BAU): To assess the sectoral energy demand, energy mix, and carbon emissions in an existing policy scenario without considering a net-zero future (implying no carbon constraint).
2. Net-Zero (NZ): To assess the sectoral energy demand, energy mix, and emissions pathway through which the state could achieve NZ emissions by 2070 (aligned with India's NZ targets). The NZ pathway to 2070 considers 2040 as the emissions peaking year (Chaturvedi and Malyan 2021), implying that the state's emissions will start declining after 2040 to comply with the carbon constraints.

Annexure I captures key data inputs, sources, and assumptions for designing these scenarios. The results provide some key insights that will be useful in setting the state's power sector transition goals.

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[5] GCAM is an energy-sector focused model that captures the interactions between different systems including energy, water, agriculture and land use, the economy, and the climate. GCAM models the energy demand of all key sectors (buildings, transport, industry, agriculture), along with various energy sources, including electricity.

- The future sectoral energy demand is modelled using projected growth in state's GDP, population, urbanisation rate, as well as technology costs, energy prices, and government policies.
- Key observations on inputs used: between 2020-2070, state GDP grows 12-fold, population rises by one-fourth, and per-capita income rises 10-fold.
- For a detailed exposition of the model, refer to Chaturvedi and Malyan (2021).

The state's power sector must decarbonise before all others.

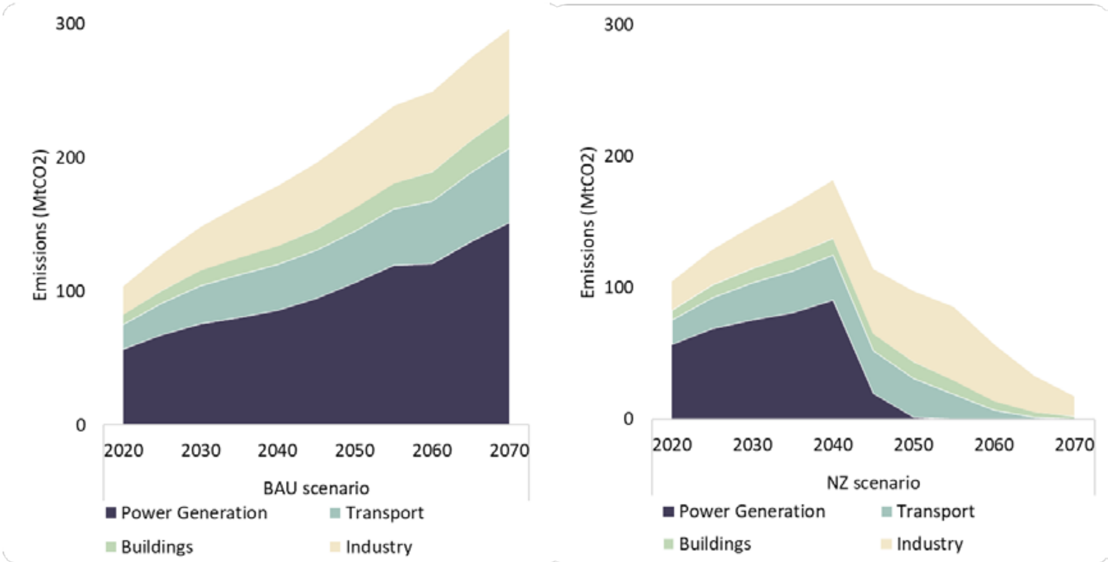
In the BAU scenario, the state's total emissions are expected to grow by 1.5 times by 2030 and nearly triple by 2070 over 2020 levels (Figure 2.1). The majority of the growth in emissions would come from the power sector, which accounted for more than half of the state's emissions in 2020. This is despite a growing share of RE in the state's electricity generation mix in the BAU.

Figure 2.1 also shows that if Rajasthan pursues a net-zero development pathway aligned with India's 2070 NZ target, the emissions would have to peak at 185 $MtCO_2$ in 2040 and decline rapidly thereafter. In this pursuit, the power sector would be the first to completely decarbonise (by 2050).

Overall, adopting a pathway to a Net-Zero economy by 2070 will allow the state to:

- Abate cumulative emissions of nearly 4.8 billion tonnes of CO_2 between 2020 and 2070 over the BAU emission levels.
- Reduce its economy's energy intensity by ~30 per cent by 2030 and 75 per cent by 2070.

Figure 2.1: Rajasthan's emissions could triple by 2070 in the BAU scenario



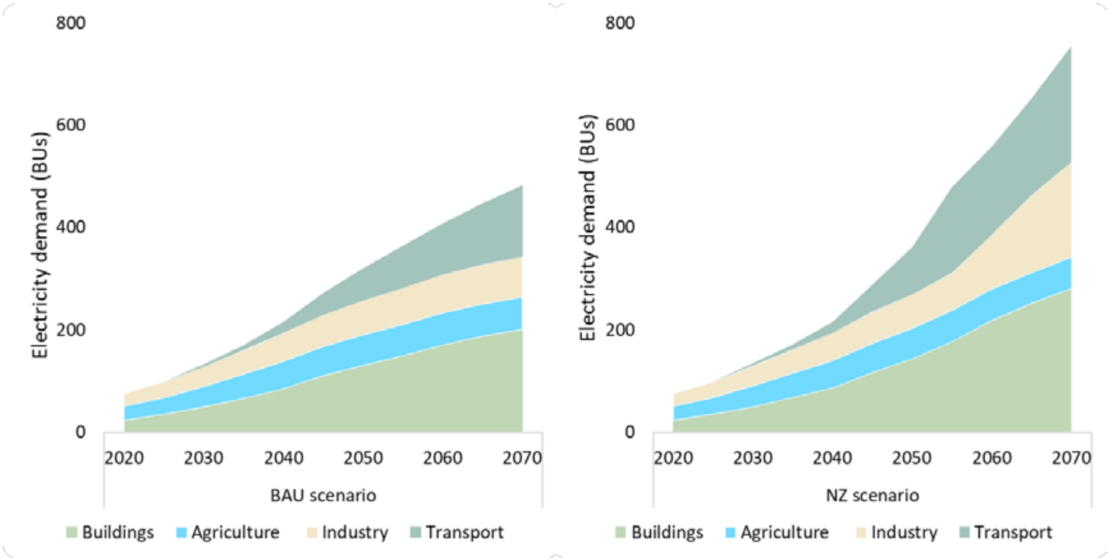
Source: Authors' analysis of GCAM results

The net-zero development pathway will result in significant electricity demand growth over the coming decades.

In the BAU scenario, Rajasthan's total electricity consumption rises by 6.4 times between 2020 and 2070 (Figure 2.2). In the NZ scenario, the power sector will serve even higher electricity demand, especially post-2050, due to aggressive electrification of hard-to-abate sectors (freight trucks, industrial processes and cooking). Figure 2.2

also shows that the NZ electricity demand in 2070 is expected to be ten times the 2020 levels and 1.6 times that of the BAU demand in the same year.[6]

Figure 2.2: The state's electricity demand in the NZ scenario will be much higher than in BAU



Source: Authors' analysis of GCAM results

Besides meeting the state's rising energy demand, Rajasthan's power sector will be a major exporter of clean electricity to other Indian states.

Due to its high RE potential, Rajasthan emerges as a major supplier of clean power to other states in both BAU and NZ scenarios. In the NZ scenario, modelling results suggest that:

- By 2030, Rajasthan's power generation (in energy terms) could increase nearly three-fold over 2020 levels. Of this, ~60 per cent could come from RE (assuming no transmission constraints and RE curtailment), equivalent to ~80 GW of RE capacity. If the demand were to rise faster (as per 20th Electric Power Survey (EPS) projections), Rajasthan may very well host around 90 GW of RE capacity.[7] As per model results, a significant share (~40 per cent) of power generation in Rajasthan could be exported to other states (assuming no transmission constraints).
- By 2070, the state's power generation would increase sixteen-fold over 2020 levels, of which 88 per cent could come from RE, and more than 40 per cent of total generation could be exported to other states. The significant jump in generation is because all states collectively go to NZ by 2070, leading to greater demand for clean power from RE-rich Rajasthan.

[6] Between 2020-2070, per capita electricity consumption of Rajasthan increases five-fold (in BAU), and eight-fold (in NZ scenario).

[7] As compared to the demand projections in the 20th EPS, GCAM's electricity demand projections for Rajasthan are lower by 32 per cent, mainly on account of higher growth in agricultural power demand projected by EPS.

In terms of fuel mix, the share of coal in the generation mix declines to 22 per cent by 2070 in the BAU, even though total generation from coal keeps rising. However, in the NZ scenario, the share of coal peaks in 2040 and declines to 1 per cent by 2050, accompanied by a major rise in solar and wind generation and nuclear energy (~10 per cent of generation in 2070). Table 2.1 summarises the model results.

Table 2.1: Projections for the electricity sector in Rajasthan

	Projections for the electricity sector in Rajasthan		BAU scenario		NZ scenario	
		2020	2030	2070	2030	2070
1	**State Electricity demand (BUs)**	75	133	483	134	754
2	**State Electricity generation (BUs)**	82	226	812	249	1312
	Generation from solar + storage (BUs)	8	95	558	107	896
	Generation from wind + storage (BUs)	9	38	61	42	265
	Generation from coal (BUs)	55	80	176	87	3
3	**Share of RE in total generation (%)**	21%	59%	76%	60%	88%
4	**Share of coal in total generation (%)**	67%	35%	22%	35%	0%
5	**Generation exported (%)**	8%	41%	7%	46%	43%
6	**Installed RE capacity (GW)**	9	72	346	80	632

Source: Authors' analysis of GCAM results

Notes: 1) Values in rows 1-5 reflect results from GCAM, while row 6 uses the RE generation values to estimate the RE capacity assuming capacity utilisation factor (CUF) of 20 per cent and 25 per cent, respectively, for solar and wind.

2.2 How can Rajasthan set up ambitious 2030 RE goals?

Based on the modelling results discussed above, the following should underpin Rajasthan's goal-setting process:

- An alignment with the national aspirations to build a Net Zero economy by 2070 and
- Setting enhanced clean energy ambitions for 2030, including achievement of 80-90 GW of RE capacity

With this, the state could meet its rising electricity demand and emerge as a major exporter of clean power to other states.

Key considerations for setting targets

As discussed above, RE will be an important pillar in Rajasthan's pursuit of a sustainable and affordable power sector. Our analysis shows that the state would have to quadruple the installed RE capacity by 2030 (~90 GW) to align with the country's net zero target. One-third of this RE capacity will be required to meet the state's renewable purchase obligations (RPO), and the rest will meet the RE demand in other states (refer to Chapter 3 for further details).

Even as the utility-scale RE will help achieve most of these obligations, a parallel emphasis on decentralised renewable energy (DRE) will be important to achieve a sustainable and people-centric power sector transition. A focus on DRE, along with large-scale RE, could support critical social, economic and developmental objectives, as listed below:

- Lower electricity subsidy burden on the state and discoms by meeting the electricity needs of subsidised agricultural consumers through DRE in a targeted manner,
- Improvement in discoms' financial health through a reduction of distribution losses and effective management of demand, which in turn will also enable large-scale RE integration with the grid and
- Creation of livelihoods through DRE-powered applications and job creation through rooftop solar deployment.

Realising these benefits is possible because Rajasthan has a huge untapped potential for DRE solutions.

- **DRE-based livelihood applications** such as grain milling, food processing, sewing machines, and paddle looms, among others, have the potential to impact more than 23 lakh livelihoods in Rajasthan (the majority being women). The market potential of these applications is close to INR 19,000 crore (Jain et al. 2023).
- **Rooftop solar** has an economic potential of 5.5 GW across residential consumers (the majority of this being in rural areas).[8]
- All the **irrigation pump sets** in the state today can be solarised through a decentralised solar capacity of 18 GW.[9]

2.3 Sizing clean energy investment needs of Rajasthan

Setting ambitious clean energy goals would present new opportunities to attract clean energy investments in the state. We estimate that Rajasthan will require investments of ~INR 5.4 lakh crore if it were to set and achieve ambitious goals of 90 GW RE capacity by 2030 (as proposed above). Below, we present the assumptions for these estimates and their break-up across investments into generation capacity, transmission infrastructure, and battery energy storage.

Power generation

[8] Economic potential refers to the technical potential where return on investment is positive for households considering factors i.e. net present value of lifetime savings is larger than the expenses. The economic potential is calculated based on IRES survey data collected by CEEW (Agrawal et al. 2020).

[9] In FY22, agricultural consumers in Rajasthan consumed 28.8 MUs of electricity (mainly for irrigation purposes) (CEA 2023a). If all of this power demand were to be met through solar power plants (deployed at feeder level), ~18 GW of solar capacity will be required, assuming a capacity utilisation factor (CUF) of 19 per cent.

Investment requirement in generation capacity is a function of additional technology-wise capacities required to meet the 2030 goals and their cost estimates. Assuming that the state's generation capacity triples between 2023 and 2030 as per the technology-mix shown in Table 2.2, an investment of nearly INR 3.8 lakh crore will be required for the same.[10] More than three-fourth of this investments will be into solar and wind power capacity. Table 2.3 provides the technology-wise break-up of cumulative investment requirement between 2023 and 2030. Table A1 in Annexure II presents the associated cost assumptions.

Table 2.2: Technology-wise projected generation capacity trends in Rajasthan until 2030 (in GW)

Technology	2023	2025	2030
Coal	11.7	13.6	16.3
Nuclear	0.6	0.7	1
Hydro	1.9	2.8	3.9
Solar	16.3	31	70.3
Wind	4.7	13.3	20.6
Total	**35.2**	**61.4**	**112.1**

Source: CEA monthly installed capacity report (CEA 2023b); Projections of technology mix are based on GCAM results.

Note: Investment sizing for biomass, gas, and refined liquids is not considered, given their relatively minor contribution to fuel mix until 2050.

Table 2.3: Rajasthan will witness an investment requirement of INR 3.8 lakh crore in power generation during 2023-2030 (in Constant 2020 INR crore)

Technology	2023-2025 (INR crore)	2025-2030 (INR crore)	Total (INR crore)	Share of investment
Coal	23,291	33,097	56,388	15%
Nuclear	3,158	9,473	12,631	3%
Hydro	11,424	13,963	25,387	7%
Solar	48,216	1,16,014	1,64,230	43%
Wind	67,658	56,282	1,23,941	33%
Total	**1,53,747**	**2,28,829**	**3,82,576**	

Source: Authors' analysis

10 These are indicative estimates and will vary with technology-mix corresponding to different demand, technology-costs, and policy scenarios.

Transmission infrastructure

Strengthening transmission infrastructure is necessary to evacuate RE generation to demand centres within and outside the state. In 2022, CEA provided a broad, pan-India transmission system roadmap for reliably integrating 537 GW RE capacity by 2030 (CEA 2022c). Of this, Rajasthan will deploy a transmission capacity for ~119 GW RE, connected to inter and intra-state transmission systems. Out of this 119 GW, integration of ~102 GW capacity is in the pre-construction or planning stage. Table 2.4 estimates the associated investment requirement for 102 GW capacity at ~INR 1 lakh crore.

Table 2.4: Investment requirement in transmission infrastructure until 2030 (in Constant 2020 INR crore)

Pan-India transmission scheme	Capacity for Rajasthan (GW)	Entity	Investment requirement (INR crore)
Transmission system for 66.5 GW ISTS connected RE capacity	3	Intra-state/ RVPN	2,250
Transmission system for 55.08 GW ISTS connected RE capacity	20	Inter-state	20,000
Transmission system for 181.5 GW ISTS connected RE capacity	70	Inter-state	70,000
	5	Intra-state/ RVPN	3,500
Green Energy Corridor (GEC II)	4		2,490
Total	**102**		**98,490**

Source: CEA (2022c)*; NITI Aayog (2015)*

Note: Cost assumptions for transmission systems are as follows: Intra-state transmission (INR 0.75 crore/MW); Inter-state transmission (INR 1 crore/MW); Green Energy Corridor (based on total GEC-II cost) (INR 0.62 crore/MW).

Battery energy storage

In addition to enhancing the transmission infrastructure and flexibility of coal-based power plants, battery energy storage systems (BESS) will be required to manage the increasing share of RE in the grid (CEA 2022c; 2023j). These storage solutions will have different applications, such as providing ancillary and spinning services and increasing the load following the capabilities of RE (CERC 2017). The requirements and locations for storage systems can be assessed based on the need and the value of these applications.

To meet the energy storage obligation (ESO) of 4 per cent in FY30 (MoP 2022), Rajasthan must procure ~6,954 MUs in that year,[11] equivalent to a diurnal BESS capacity of 4.8 GW with 4-hour storage. It will create an opportunity for BESS projects worth more than INR 55,600 crores until 2030[12] (Table 2.5). Recent independent assessments for Rajasthan also suggest that by the end of 2025, with 30 GW solar and 5 GW wind, 4.4 GW of 2-hour battery energy storage systems would be cost-effective (Chernyakhovskiy et al. 2022). However, to meet the 90 GW RE target, the state may see a much larger storage capacity in line with the evolving deployment models, transmission constraints, and the need to minimise RE curtailment, as discussed in Chapter 3. Accordingly, additional investments will be needed for storage capacities.

Table 2.5: Total storage investment requirement until 2030 (in INR Crore)

FY	Daily energy storage (in GWh)	Daily energy storage with round-trip efficiency (in GWh)	Daily energy storage with depth of discharge (in GWh)	Additional daily energy storage requirement in the year (in GWh)	Capex (in USD/ kWh)	Storage investment required (in INR crore)
	(F)=(C)/365[13]	(G)=(F)/0.85	(H)=(G)/0.90	(I) = (H)-(H-1)	(J)	(K)=(J)*(I)*82/10
2023-24	2.47	2.90	3.2	3.2	400	10,572
2024-25	3.95	4.64	5.2	1.9	400	6,343
2025-26	5.64	6.64	7.4	2.2	380	6,919
2026-27	7.53	8.86	9.8	2.5	361	7,315
2027-28	9.62	11.31	12.6	2.7	343	7,654
2028-29	11.89	13.99	15.5	3.0	326	7,941
2029-30	14.58	17.15	19.1	3.5	310	8,908

Source: Authors' analysis based on stakeholder consultations; CEA (2022a); Chaturvedi and Malyan (2021)

Note: Currency conversion rate considered for 2020 at USD 1 = INR 82

As RE deployment accelerates, Rajasthan must provide an environment for early investments in energy storage solutions across various applications and identify the operational models and technologies best suited for the state.

11 Assuming that Rajasthan will consume 133 BU of electricity as per the 20th EPS and will meet the 4 per cent ESO through battery storage systems that will have a roundtrip efficiency at 85 per cent and depth of discharge at 90 per cent.

12 Authors' analysis considering the present cost of BESS as USD 400/kWh declining to USD 310/kWh in FY30.

13 Refer to Table A2 in Annexure II for annual energy storage requirement.

The state should strive to create an attractive ecosystem to mobilise such investments from diverse sources. These include domestic banks, non-banking financial institutions like IREDA, REC, PFC, and IIFCL, multilateral agencies like the World Bank and Asian Development Bank, and international asset managers and owners (Chaturvedi and Malyan 2021; Standard Chartered 2022). Central and state financial assistance would also be crucial to crowd in private investments.

3. TOWARDS COST-EFFECTIVE INTEGRATION OF RENEWABLE ENERGY

As of June 2023, Rajasthan leads RE deployment in India, with more than 23 GW of solar and wind, constituting 58 per cent of the state's total generation capacity (CEA 2023b). The state aims to reach 37.5 GW of renewables by 2025, which can go up to 90 GW by 2030. Pursuing these targets would imply a significant increase in VRE's share in the state's electricity mix and the export of huge quantities of RE. These would present new challenges concerning the cost-effective integration of VRE while ensuring secure and reliable power system operations. This chapter outlines key challenges to solve, assesses the need and the role of various generation sources and flexible options for optimal system dispatch, and suggests some interventions that could bolster the state's efforts to absorb high shares of VRE.

3.1 System operation challenges for Rajasthan with VRE at scale

High penetration of VRE can impact the state's system operations in four ways, as discussed below.

1. **RE variability**[14] induces steep changes in the load to be served using resources other than RE (also known as net load). Non-availability of RE through the day or varying availability through the seasons or days requires the existing thermal fleet to operate only at part capacity for certain hours and ramp swiftly. It also requires a seasonal balancing of demand and supply. Figure 3.1 reflects this phenomenon for Rajasthan's system across sample days in 2030.
2. **RE uncertainty**[15] makes real-time balancing demand and supply challenging because of sudden and unanticipated spikes and dips in net load (Figure 3.1). Dealing with this uncertainty requires flexible resources to be available instantaneously as and when needed. Without fast-response resources, the grid may see voltage and frequency fluctuations, affecting grid reliability at the transmission and distribution levels.

The impacts of RE variability and uncertainty will increase Rajasthan's ramping requirement[16] by four-fold between now and 2030 (Figure 3.2), implying that system

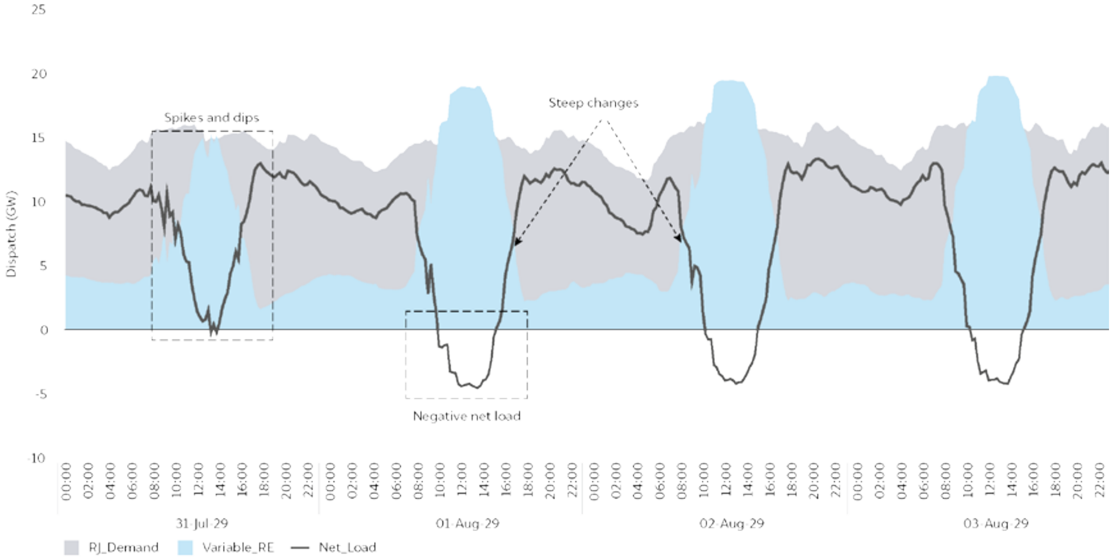
[14] RE variability is the natural and known variation in energy generation from RE sources. For example, solar energy is present only during the day. Traditionally, such variability is observed only on the demand side, for example, low demand during monsoons or high demand during summer evenings.

[15] Refers to the inability of precisely and accurately predicting RE generation in future, even with advanced tools and methods to forecast close to real time.

[16] Ramping need is indicated by the variation in the net load between two consecutive time blocks

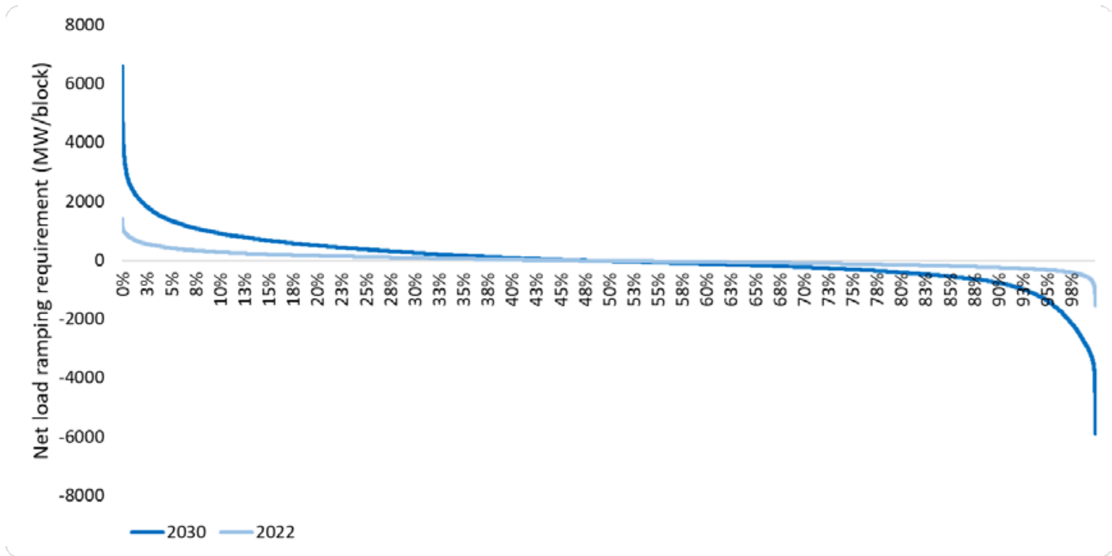
flexibility, both on the supply and demand sides, must increase significantly (refer to Box 3.1).

Figure 3.1: High VRE shares will introduce complexities for Rajasthan's system planners and operators



Source: Authors' analysis using demand projections as per CEA 20th EPS and RE generation corresponding to the capacity needed for meeting Rajasthan's 2030 RPO target (assuming must-run status of RE)

Figure 3.2: Rajasthan's 15-minute net load ramping requirement increases 4-fold by 2030



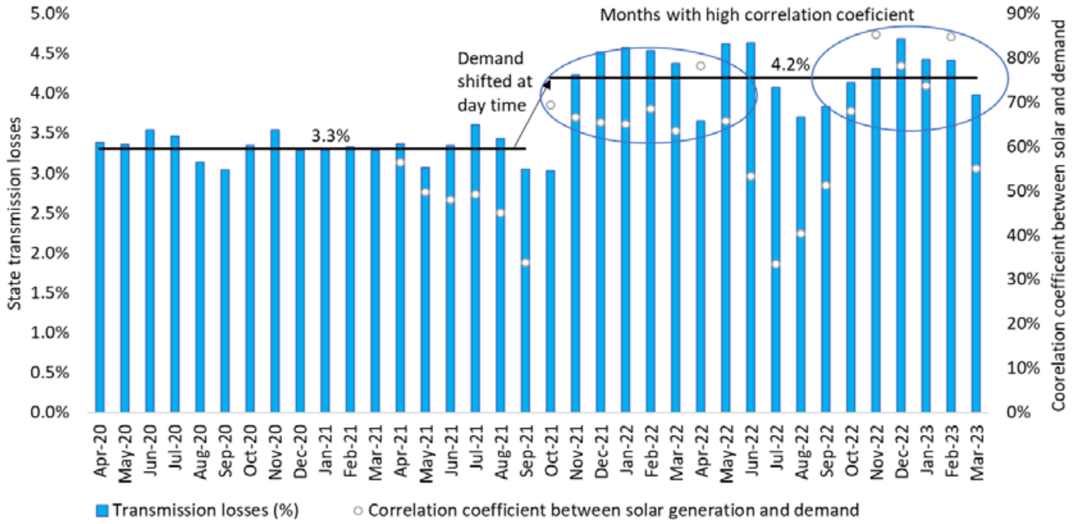
Source: Authors' analysis of the current and future net load profiles for the state

Notes: (1) The x-axis shows the percentage of 15-minute time blocks in a year in which a given ramping capacity is required. (2) 'Net load' is computed as a difference between demand and RE generation at each time block. (3) Here, 2022 corresponds to July 2021 to June 2022, and 2030 corresponds to July 2029 to June 2030.

3. Instances when peak RE generation coincides with low demand periods lead to **negative net load** (i.e. RE generation is greater than demand). Occurrences of negative net load imply that the grid needs energy storage capabilities to store surplus RE generation (mostly during peak sunshine hours) and utilise that to meet the load when it increases (e.g., during evenings or early mornings). For reference, as per our model, the state system could observe more than 300 hours of negative net load, during which 582 MUs of excess RE will be generated. If storage solutions are not deployed or excess generation is not transmitted to meet demand in other states/ regions, this **excess RE will be curtailed**.

4. RE technologies, especially solar, **provide no inertial or reactive power support**, thus increasing transmission system losses.[17] Rajasthan has already started seeing higher transmission loss levels while utilising solar power to meet demand during the daytime (indicated by the correlation coefficient in Figure 3.3). Avoiding these losses and maintaining the line loading capacities require investments (mostly one-time) in infrastructure upgrades. In addition, deploying decentralised renewable energy (DRE) solutions to meet demand close to the load centres can also help address this challenge that otherwise arises with large capacities of utility-scale RE connected to the transmission grid.[18] For example, feeder solarisation under the KUSUM scheme is a solution the state can scale up to serve the agriculture demand during the day.

Figure 3.3: Intrastate transmission losses have been increasing, creating a hurdle in shifting demand to daytime



Source: Authors' analysis based on Rajasthan state energy accounting provisional reports (Part B) for April 2020-March 2023 (Rajasthan SLDC, n.d.)

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17 To transfer the power from one node to the other, the transmission line consumes some part of electricity (called reactive energy). Losses are the difference between the energy withdrawn and energy injected. Aggregated loss of each line in the network is considered as transmission system losses.

18 DRE avoids transmission and distributed losses, buildout of infrastructure, is land use effective and has multiple applications in providing grid services.

Box 3.1: What is electricity system flexibility

Electricity system flexibility refers to the ability of the system to adjust and respond to changes in electricity supply and demand in a timely and efficient manner. Ensuring this balance cost optimally is the primary constraint towards decarbonising our power system.

Demand and supply of electricity need to be balanced at all times. Any variation in either can lead to fluctuations in the network's voltage and/or frequency. Depending on their severity and duration, the imbalances can lead to several consequences, such as damaged equipment, power outages, increased cost, and grid failure. System balancing requirements underpin mechanisms like deviation settlement that attempt to enforce grid discipline amongst the power generators and the buyers.

In a power system, sudden supply variations can occur due to unexpected generation outages or equipment failures. Weather patterns can also cause demand fluctuations. However, such long-term variations have more economic impact rather than technical consequences. For example, if the suppliers do not anticipate these changes adequately, it could lead to the underutilisation of existing resources or the purchase of costly power at short notice. System flexibility is essential to manage the fluctuations, variations, and uncertainties across time horizons.

3.2 Assessing the flexibility requirements and solutions

We must examine the changes that the state's capacity and generation mix would undergo between 2022 and 2030 to identify the strategies for meeting increased flexibility needs. We, therefore, modelled two distinct cases for the system dispatch in the future. Across both cases, we analysed why and how the flexibility needs and system responses would change by 2030.

Through the first case, we aim to understand the flexibility requirements of the national grid with 500 GW of non-fossil capacity and the role that the generation assets installed within Rajasthan's periphery will play in managing the grid. This case considers load-generation balance at the national level. In the second case, we examine the requirements of the load-serving entities (i.e., the discoms) in Rajasthan to meet their renewable purchase obligation (RPO) targets. Here, we consider a typical situation where the state balances the demand and the generation on its own.

Case 1: Rajasthan installs 90 GW RE to support India's energy transition goals while also meeting its energy security and decarbonisation objectives

Here, we undertake a national-level dispatch optimisation exercise using GE MAPS[19] where Rajasthan is modelled as a node with 90 GW of VRE installation and other states as separate nodes. We model each node with a set of generators and load profiles. The power is free to flow from one node to the other subject to import and export transfer limits between regions and states. The balancing area thus expands to the entire country.

The entire system is then simulated to obtain the least-cost dispatch at a 15-minute level, such that annual curtailment at the national level is less than 5 per cent and the unmet demand (or energy not served) is less than 0.5 per cent. The simulations include supply-side flexibility options such as pumped storage hydropower (PSH), flexibilisation of the state's existing coal fleet by lowering the minimum technical load (MTL)[20] levels of coal-based units to 40 per cent of their rated capacity, and battery energy storage system (BESS) to achieve these curtailment levels.

We adopt the standards the CEA assumed on annual availability, operational characteristics and constraints of the thermal fleet, and demand and supply projections (CEA 2022a; 2023j; 2023g). Annexure IIIa captures the detailed inputs and assumptions for this case.

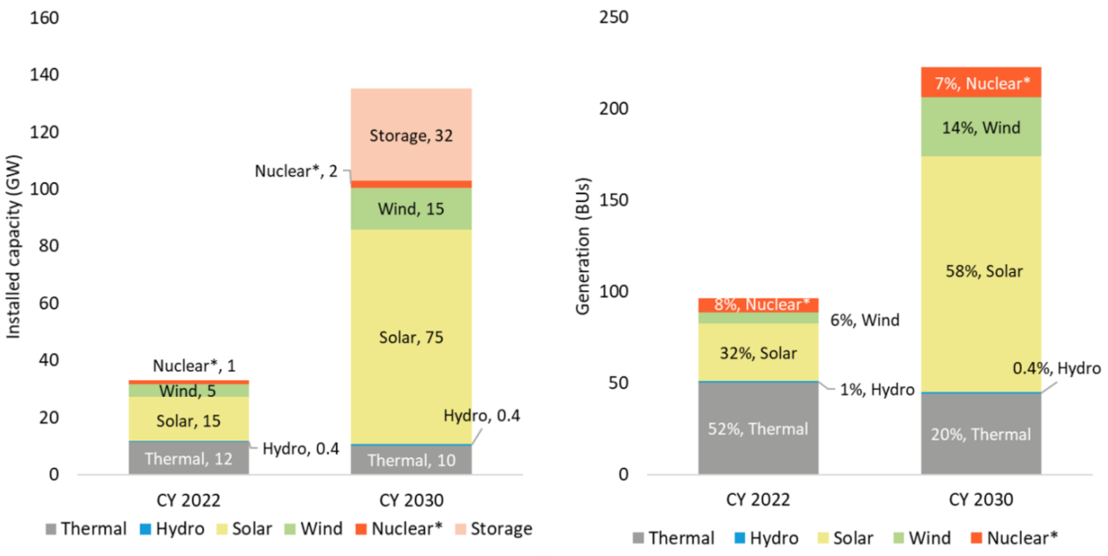
Key Insight: To integrate 500 GW at the national level by 2030, with 90 GW in Rajasthan, the system's flexibility needs will increase substantially.

By 2030, Rajasthan could emerge as a RE powerhouse of India, where 90 GW VRE is making up more than 70 per cent of the generation within the periphery (Figure 3.4), which is double the share of VRE at the national level as per the all-India dispatch simulation. Nearly one-quarter of the entire energy generated within the state is exported, mostly during the daytime.

[19] General Electric (GE) Multi-Area Production Simulation (MAPS) is a dynamic python-based tool utilised to simulate the national power sector, where each state is modelled as a node along with inter-state transmission and system operational constraints (GE Energy Consulting n.d.).

[20] MTL: Minimum technical load is the loading level, up to which the plant can hold its generation stable, if the plant is operated below this level, it will shut down. But by retrofitting the control system and other equipment, it is possible to lower the MTL.

Figure 3.4: With 90 GW of RE in Rajasthan, VRE share in generation rises to 72 per cent

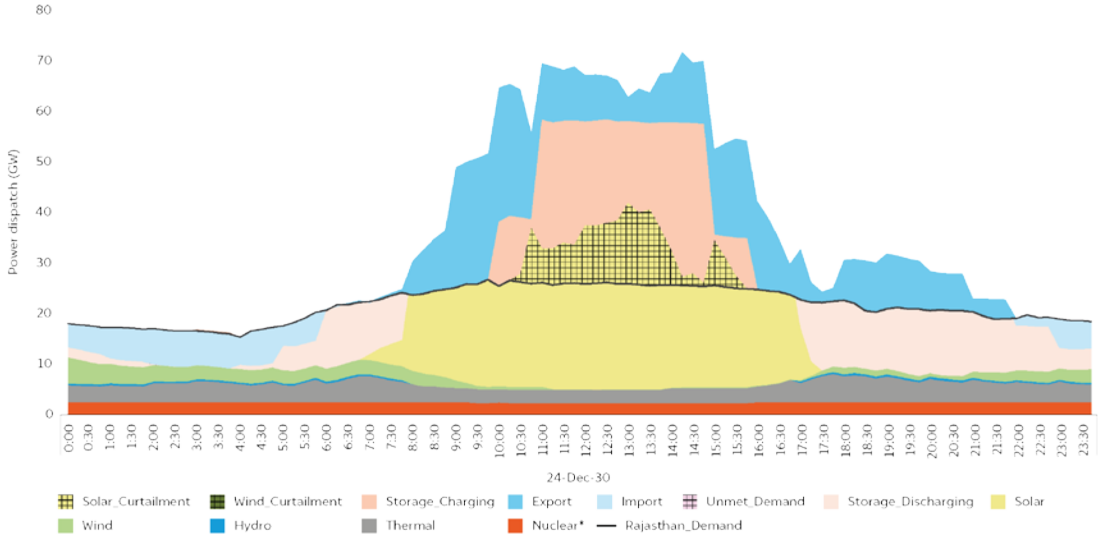


Source: Authors' analysis of modelling inputs and outputs specific to Rajasthan for case 1 (all-India dispatch)

Note: (1) 'Thermal' includes coal and gas-based plants, and 'Nuclear*' predominantly includes nuclear, along with bio-energy and small hydro projects (SHP). (2) The base year is considered as the calendar year (CY) 2022.

On a day in 2030 (24 December), Rajasthan experiences peak demand of almost 27 GW at 0945 hours (Figure 3.5). On this day, **storage and flexibility options play a critical role in managing the supply-side variations, minimising RE curtailment while meeting the peak demand at the same time.** Rajasthan sees a demand of 520 MUs on this day. There is a wide variation in RE between peak and off-peak generation times. Excess generation equals 131 MUs during the day, including 117 MUs of net exports and 14 MUs stored for later use. Adding storage and increasing coal fleet flexibility restricts RE curtailment to 8 per cent of the total RE generation at the Rajasthan periphery (checked region in Figure 3.5), which would have been greater than 50 per cent in the absence of these solutions. Figure 3.5 also shows that the energy is stored when solar is at its peak and used during early morning and evening/night hours to meet the peak demand. **The electricity exports to other states mostly happen during the daytime, coinciding with peak solar hours** (blue curve in Figure 3.5).

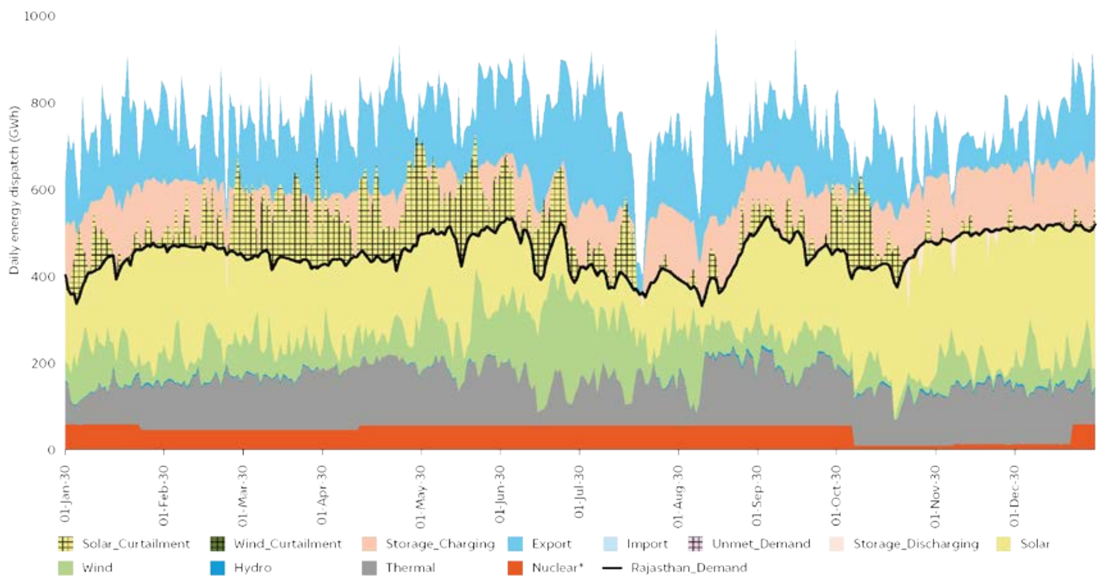
Figure 3.5: Storage will play a key role in meeting peak demand and reducing RE curtailment



Source: Authors' analysis for maximum demand day observed in Rajasthan in case 1 modelling results

The integrated system dispatch shows that **Rajasthan would be a leading contributor to the national RE goals and serve a considerable share of India's flexibility needs.** This is evident by looking at the daily dispatch for 2030 (Figure 3.6). Throughout the year, there are significant amounts of exports (area in blue) such that the state becomes a net exporter from being a net importer until recently. By ensuring the deployment of flexible resources (in the form of BESS and a more flexible coal fleet), the annual curtailment at the national level could come below 5 per cent.

Figure 3.6: Rajasthan could export a net of 50 BUs electricity in 2030

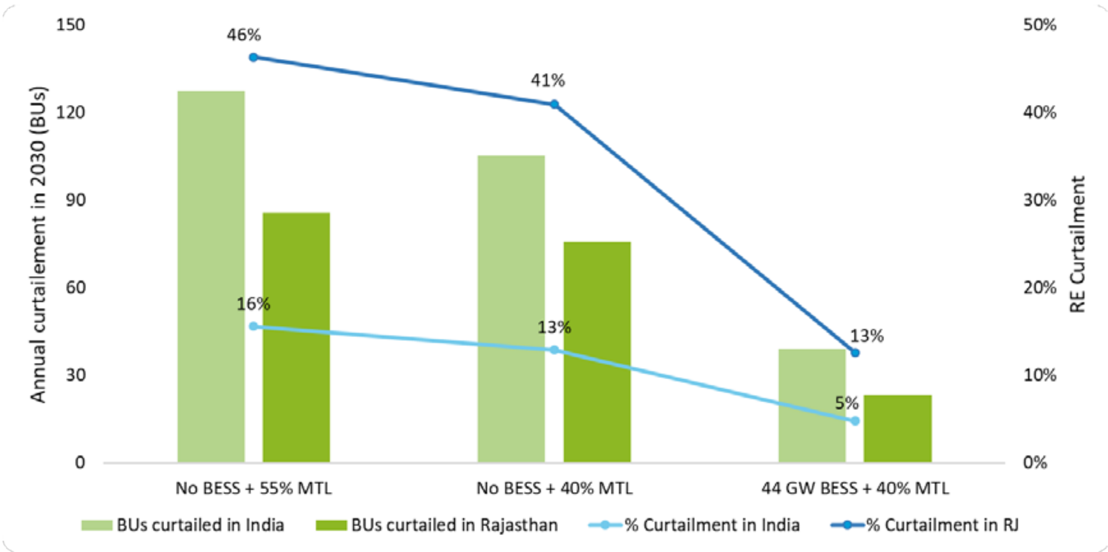


Source: Authors' analysis of the case-1 dispatch outputs

Note: Till FY22, Rajasthan was a net importer of electricity. In FY23, Rajasthan's net exports amounted to 4 BUs (CEA 2023d; 2023f; 2023h).

At the national level, RE curtailment can be reduced from 16 per cent to 13 per cent by lowering MTL levels of select coal-based units, equal to 74 GW of net capacity (Figure 3.7).[21] Lowering the MTL from 55 per cent to 40 per cent of rated capacity can help absorb an additional 22 BUs of RE at the national level. Of this 74 GW capacity, Rajasthan's net coal capacity comprises 7.8 GW (Table 3.1).

Figure 3.7: Rajasthan's VRE curtailment can reduce from 46 to 13 per cent via a series of interventions



Source: Authors' analysis based on sensitivities modelled under case 1

Table 3.1: Around 74 GW of coal capacity must be retrofitted for lower MTL, of which 7.8 GW is in Rajasthan

Net capacity (number of units)	Rajasthan	India
State sector	6.3 GW (19)	29 GW (58)
Central sector	0.2 GW (1)	25 GW (52)
Private sector	1.2 GW (2)	20 GW (37)
Total	**7.8 GW (22)**	**74 GW (147)**

Source: Authors' analysis based on the criteria to select units for retrofitting

Note: The generating units operating near their MTL of 55 per cent during the time blocks when RE-rich states observed curtailment were identified and listed until 81 GW gross (rated) capacity is reached. 81 GW is equivalent to centrally-owned capacity.

We also note that **44 GW of 4-hour BESS helps absorb an additional 66 BUs of RE at the national level** (Figure 3.7). Of this 44 GW of BESS capacity, 32 GW will

21 Net capacity indicates gross (rated) capacity minus the capacity corresponding to auxiliary consumption throughout the year.

need to be located in Rajasthan,[22] thus contributing to the national storage requirement and minimising curtailment at the Rajasthan periphery. Additional measures, such as increased BESS deployment or higher ramping rates of the thermal fleet, may further reduce the curtailment levels. However, considerations concerning low utilisation levels of additional BESS or increased investment requirements for retrofitting thermal units will need to be accounted for while devising the flexibility roadmap.

Case 2 - Rajasthan discoms contract additional capacities to serve their demand while complying with their RPO targets (state-level model)

While Case 1 demonstrates Rajasthan's role in meeting India's national RE ambitions, the objective of Case 2 is to understand how Rajasthan's contracted energy mix will change if the state meets its RPO targets while serving its demand. Here, our objective is to understand the planning and operational challenges and the flexibility requirements that would arise for the state agencies.

In this case, we use an open-source model, GridPath[23] , where Rajasthan is modelled as a single node using a copper plate approach (i.e., without intra-state transmission constraints). The model considers the state's existing and planned contracted capacity and forecasted demand as per CEA's 20th EPS (CEA 2022a). The availability of plants accounts for planned maintenance schedules (8 per cent of the time) and unplanned outages (7 per cent of the time) as per CEA standards. The model finally optimises the cost of dispatching for the generators contracted by the state to meet the demand subject to 55 per cent MTL and other operational constraints as described in Annexure IIIb.

Key insight: Rajasthan discoms will need robust resource adequacy planning to meet the rising electricity demand

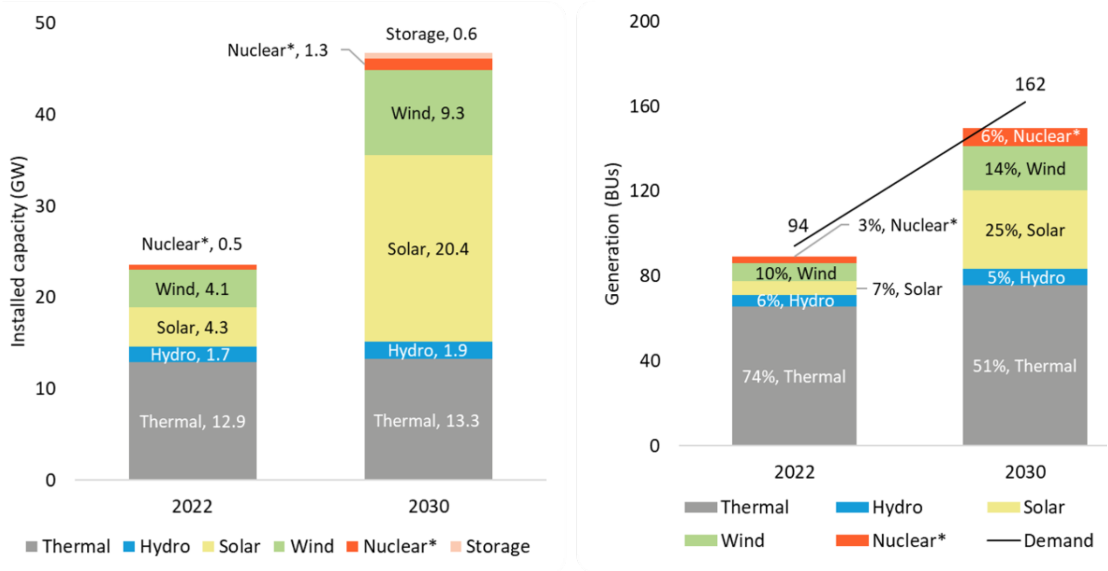
Rajasthan discoms would need 29.7 GW of solar and wind capacity by 2030 to meet the RPO targets. The 29.7 GW consists of 16 GW solar and 5.1 GW wind in addition to 4.3 GW solar and 4.1 GW wind contracted as of 2022. Figure 3.8 represents the growth in contracted capacity till 2030 and the energy generation mix

[22] Storage is sited in the states where significant RE curtailment is observed. In the modelling exercise, curtailment is observed mainly due to (a) no demand to be serve within or nearby states (2) constraints in the transfer capability within the inter-state network. The storage capacity is substantial in Rajasthan because it is the largest RE generator in 2030, with 90 GW installed capacity (against a peak demand of 26 GW). Solar is dominant, making up 83 per cent of this installed capacity. As a result, surplus solar generation is seen during hours when inter-state transmission capability to export power is exhausted, resulting in high curtailment and the need for storage capacities to reduce the same.

[23] GridPath is an open-source grid analytics tool developed by Blue Marble Analytics (Blue Marble Analytics n.d.) using which we have modelled Rajasthan's power contracts to meet the forecasted demand, subject to system constraints as discussed in Annexure IIIb. The tool has also been used to conduct a similar study for Maharashtra (Dukkipati et al. 2021).

to meet the expected demand. The share of RE increases from 17 to 39 per cent by generation, in compliance with 7 per cent RPO for wind and 29 per cent RPO for solar (MoP 2022).[24] The share of thermal generation reduces from 74 per cent to 50 per cent to accommodate a high VRE share.

Figure 3.8: Rajasthan will need an additional 21 GW VRE to meet its 2030 RPO targets



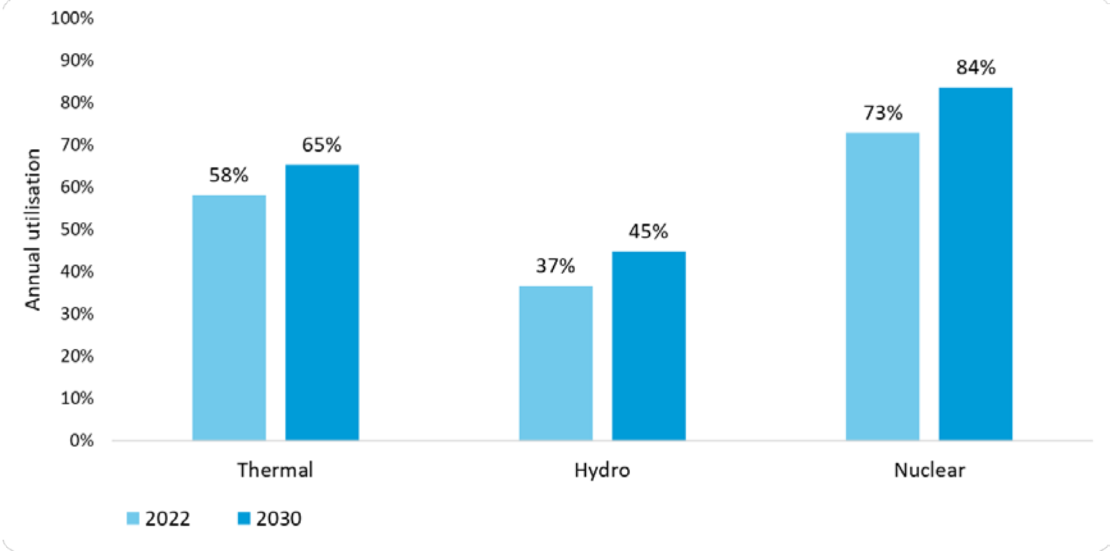
Source: Authors' analysis of the contracted capacity data and the corresponding generation under case 2

Notes: (1) 'Nuclear*' predominantly includes nuclear along with bio-based energy and small hydro projects; 'Thermal' includes coal and gas-based projects. (2) The generation results for 2022 are actual as reported by SLDC and Northern Regional LDC in the daily implemented schedule reports. (3) The July 2021 to June 2022 period is considered for 2022 and similarly for 2030 to negate COVID-19's impact during initial months of FY22. (4) Two units of Giral TPP (250 MW) are excluded because they are in permanent outage as per CEA's operational performance monitoring reports on the thermal fleet (CEA 2023i).

To cater to the increase in demand (that will almost double between 2022 and 2030) and to accommodate variability in RE, the annual utilisation of conventional sources, such as thermal and hydro, increases slightly (Figure 3.9).

[24] Solar is considered as part of the 'others' category in the national RPO trajectory, this also includes generation from wind power plants commissioned before March 2022.

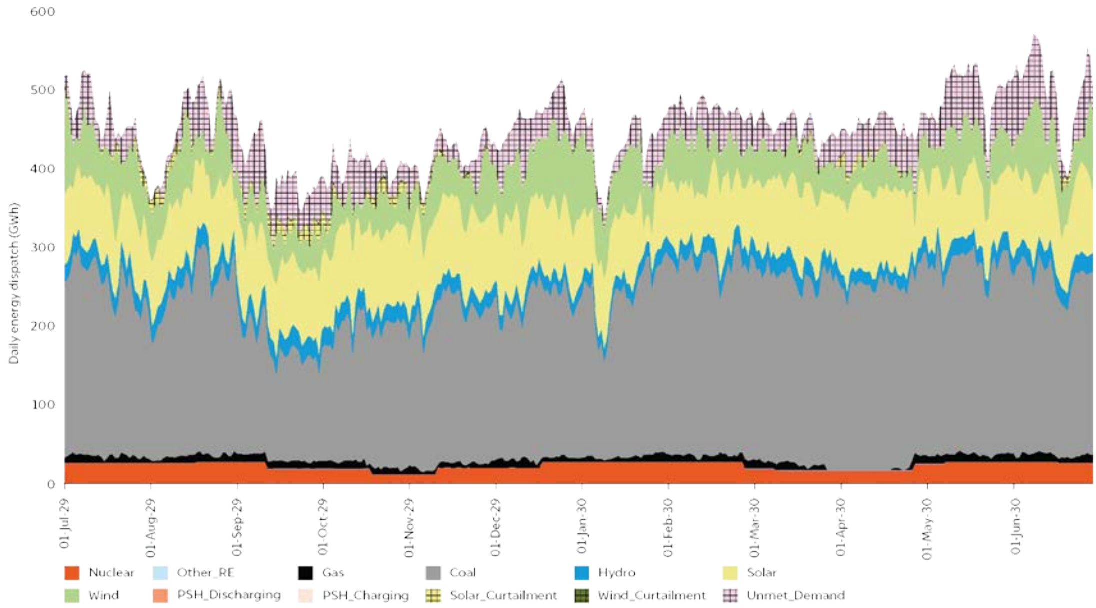
Figure 3.9: Utilisation of conventional sources in Rajasthan will increase to meet increased demand by 2030



Source: Authors' analysis of case 2 dispatch results

Figure 3.10 shows that despite meeting RPO targets and higher utilisation of existing and planned conventional capacities, the state observes 7 per cent of unmet demand[25] (dotted purple area) and 3 per cent RE curtailment (chequered yellow region) annually. We also observe that the unmet demand occurs during low or no solar hours (Figure 3.11).

Figure 3.10: Under existing plans, while RPO can be met by 2030, 7 per cent of demand would remain unmet, indicating the need for more resources

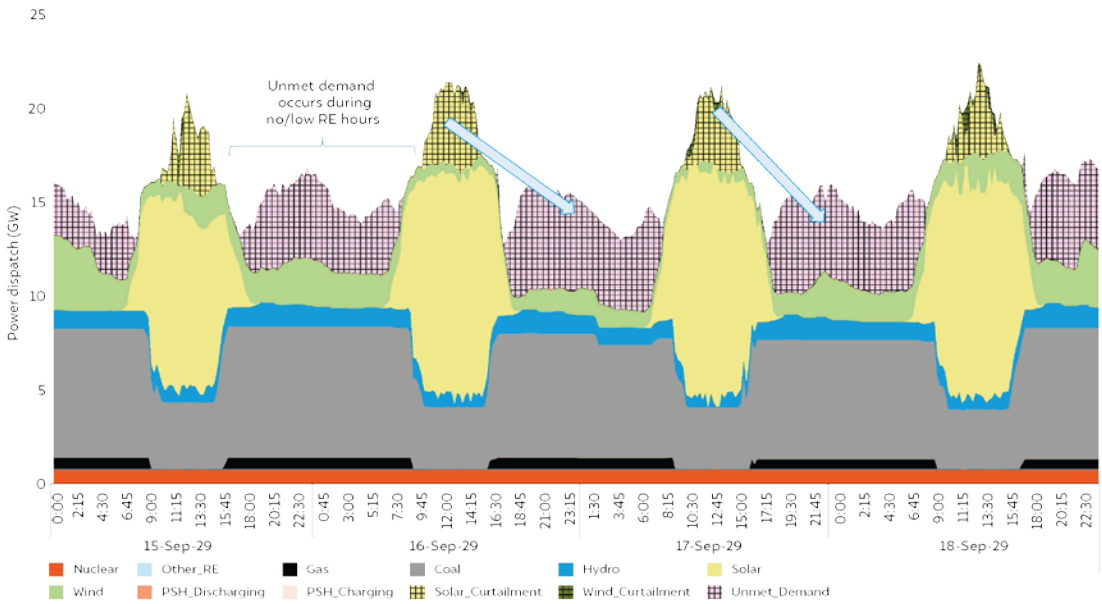


Source: Authors' analysis based on dispatch results obtained from case 2

Note: 'Other_RE' includes Bio-Energy and small hydro projects (SHP)

25 In 2022, 5 per cent of the energy served is procured via open access, market platform and banking.

Figure 3.11: Unmet demand typically occurs during non-solar hours



Source: Authors' analysis on sample days selected from the annual dispatch in 2030 (Case 2)

Figure 3.11 also highlights the flexibility behaviour demonstrated by different resources. For instance,

- Gas supports the load by starting up and shutting down frequently
- The coal fleet gets reduced to its possible technical minimum level (55 per cent in this case) during solar hours.
- Hydro is generally treated as a base generator. However, during high-RE hours, it is used to accommodate the supply-demand variations and the operational constraints of the coal fleet.

We also observe months with RE curtailment and no significant unmet demand (Jul-Aug) in Figure 3.10. The surplus RE generation during these months can be utilised to meet the unmet demand during other months through the development of long-duration storage solutions, such as PSH plants. The state has already planned to contract 590 MW of PSH by 2025,[26] which has been modelled under case 2.

Days with curtailment and unmet demand demonstrate the need for diurnal energy storage solutions and additional resource requirements in the system. Once the curtailed RE is planned to be stored and used later to meet the unmet demand, additional storage, short-term market avenues, and banking can be tapped to reduce the unmet demand further.

We compare three routes that the discoms may take to meet their additional resource requirements by 2030:

[26] As per inputs received from Rajasthan Urja Vikas Nigam Limited (RUVNL).

1. **Round-the-clock (RTC) solar:** An additional 3.7 GW[27] solar, along with BESS capacities, to store most of the power generated during non-solar hours. In 2025, such a capacity designed to store 50 to 70 per cent of solar energy is expected to cost ~INR 4.34 to 5.15/kWh, respectively (Deorah et al. 2020), and the costs may go down further by 2030.
2. **Additional wind capacity:** 3.2 GW additional wind capacity (at 28 per cent capacity utilisation factor (CUF)) could also generate power during non-solar hours. Wind availability coincides more with the residual unmet demand and may require less storage. Wind power may also be better utilised if long-duration storage options can be developed to meet high unmet demand during non-windy months.
3. **New thermal capacity:** 1.5 GW[28] of additional coal-based capacity operating at ~60 per cent utilisation annually. This capacity may need to operate only for ~15 hours in a day (non-peak-solar hours). New coal units are expected to supply power at >INR 5.5/kWh in 2030 (with a 2 per cent annual cost escalation[29] on a recent bid for Obra ultra-supercritical unit - INR 4.79/kWh) (The Indian Express 2023).

With high VRE shares, the average utilisation of several thermal units will reduce as they are likely to operate at lower MTLs and witness frequent start-stops. As a result, their fixed cost implications and operating costs will increase. With competitive price discovery in recent tenders, RTC renewables or wind-solar hybrid projects are emerging as economically attractive solutions.[30] Given the fast-evolving market landscape, the state must conduct detailed resource adequacy studies to identify the appropriate capacity mix and create a conducive ecosystem to attract investments in desired technologies.

[27] Authors' calculations assuming residual unserved energy (8 BUs) will be generated by solar at an annual CUF of 25 per cent.

[28] 1.5 GW capacity corresponds to meeting the requirement for almost half of the year. Further increasing this capacity may not be financially viable because of low utilisation and therefore, market-based routes may be preferable.

[29] Rajasthan Discoms' petition for approval of true-up of FY 2021-22 to RERC-Petition No. RERC 2066/2022, 2067/2022, 2068/2022.

[30] SECI auction for RTC RE concluded in May 2020 discovered a levelised tariff of INR 3.6 per kWh over 25 years (NetZero Pathfinders 2021).

3.3 Key Recommendations for Cost-Effective RE Integration in Rajasthan

Rajasthan must utilise diverse, flexible supply and demand-side resources to integrate large shares of VRE, guided by adequate planning tools and supported by a smart and reliable grid.

A. Adopt integrated resource planning to guide investments in the right technologies and solutions:

Our analysis confirms that meeting the 2030 RE goals would require Rajasthan to turn to diverse generation sources to manage the RE variability and uncertainty while meeting the rising energy demand. An integrated resource planning (IRP) process becomes essential to ascertain the right mix of technologies. The IRP considers both demand (energy efficiency, demand response, demand shifting, etc.) and supply-side resources to meet the system's future needs under various uncertainties and scenarios. For instance, IRP exercises can help planners optimise between immediate system requirements and the long-term viability of investments, accounting for various demand scenarios and impacts of factors such as changes in battery costs, fuel prices, electricity market prices, and policy incentives.

The Government of India has proposed integrated resource planning guidelines (MoP 2023c). To translate central guidelines into state-level action, RERC should incorporate CERC’s resource adequacy guidelines in the state Grid Code and clearly outline the roles and responsibilities of the various entities in resource planning and demand forecasting. RERC should also mandate IRP submission as part of the ARR process and establish an IRP evaluation desk at RERC.

On their part, Rajasthan discoms, along with RUVNL, must conduct system studies to determine resource adequacy needs, including planning reserve margin. For this, they could use open-source simulation tools in collaboration with sector experts. Any IRP must consider RE, storage and conventional resources, market-based procurement, distributed energy resources (DERs), and demand-side management (DSM) measures such as demand shifting or solarisation of agricultural demand. For a robust IRP, discoms must conduct granular demand forecasting for different consumer segments every year for a 5-year horizon. Subsequently, discoms should develop an IRP every 3 years for a 10-year horizon to inform capacity planning. The state must allocate funds to enable its institutions to adopt new tools, acquire knowledge of best practices, ensure staffing for the identified roles, collaborate with technical institutions, and conduct progress monitoring and review of activities.

B. Enable state resources to participate in national wholesale markets for efficient use of resources and reducing price volatility risks, thereby aiding higher RE absorption:

Ministry of Power's recent report on power market design proposes a nationwide economic dispatch model (starting with the SCED and eventually moving to the MBED) to be adopted in the near term (MoP 2023b). It also envisions a capacity market that enables resource sharing and deepening of the existing market segments,[31] including the ancillary services market (ASM)[32] and retail markets guided by the distribution system operator (DSO).[33] The CERC has already notified the regulations to create a market for ancillary services, which includes resources connected at the STU level.[34]

However, the states must address the challenges accompanying the deepening of markets in coordination with the MoP and the CERC. The challenges around potential inflexibilities in scheduling and revision of schedules must be addressed for the national markets to operate efficiently. For example, the states can reduce their dependence on their right to recall by improving demand forecasting accuracy. Further, the states can take actions that help increase liquidity in the national markets. For instance, states can ensure better utilisation of PPA-tied generating plants by facilitating resource-sharing with other states. Discoms and the SLDCs can activate demand response at the state level that may then participate in the national market. Rajasthan could be the leader in contributing to these reforms with its discoms, regulator, and SLDC by anticipating these changes and participating in efforts on market design development.

C. Enhance supply-side flexibility through diverse options

a. Targeted and timely interventions to make select coal-based units flexible.

If coal plants need to serve the load during non-VRE hours within a short period, they need to be in an operating state (i.e. at or above MTL). This is because their start-up time (if stopped) is high relative to gas or hydro. Further, to reduce the response time, they must ramp fast. However, doing so without any interventions can cause thermal stress on the equipment, increasing operational costs. Plant MTLs can be lowered with technology advancements and retrofitting. Control mechanisms like automated generation control (AGC) can be retrofitted in existing plants to provide secondary

[31] The existing market segments on the power exchange are real-time, day ahead, term ahead, and the contingency market segments for each of RE and non-RE.

[32] It is a tool to activate the balancing resources timely and at least cost. In the Indian context, in case of any imbalance event on the grid, the primary response measures are initiated within 5-10 seconds and sustain up to 5 minutes. The secondary and tertiary responses are those that can be initiated in 30 seconds and 15 minutes respectively. Generating stations, entities capable of providing demand response, or entities having energy storage resources, whether individually or on an aggregated basis, and connected to the inter or intra state transmission network are eligible to participate in the ASM.

[33] In the future, the state's public discoms would likely evolve into distribution system operators (DSOs) who will be responsible for managing the network and providing network access and grid services to multiple electricity retailers

[34] Previously, only ISTS enabled plants with requisition surplus were providing ancillary services.

responses. Retrofits can also help increase the ramping rates and decrease the start-up time (from a warm or hot start).

Our analysis suggests that the state's existing coal fleet is not flexible enough to meet the future ramping requirements.[35] For instance, the MTL of some units ranges between 65 to 75 per cent, distinctly higher than the CEA standard of 55 per cent (CEA 2019a). Similarly, most plants show a ramp rate of 0.50 - 0.77 per cent of rated capacity per minute, lower than current standards of 1 per cent per minute.[36] As per our assessment, the existing thermal capacity can currently provide 880 MW/block of ramping capability, which can be doubled by adhering to CEA standards.

Thus, RERC must update the state Grid Code to define the operational standards for thermal power plants in line with CEA norms. Further, the Government of Rajasthan must engage with the state-owned generating company to operationalise retrofitting measures, with the unit-level decisions being informed by a thorough cost-benefit analysis.

Our analysis also shows that flexible units within the state will serve the balancing needs at the national level as market-based dispatch mechanisms are implemented. Therefore, the state must coordinate with the central government to devise appropriate compensation mechanisms that encourage timely investments in retrofitting units.

b. Ensure storage solutions at various levels to enhance flexibility further, manage demand, and provide ancillary services:

Storage has numerous applications, such as storing and releasing electricity based on availability and cost, providing real-time control, and assisting in load management, peak shaving, power backup, and more. To meet the anticipated electricity demand and realise the RE targets, CEA has estimated that the national power system will require 41,650 MW/2,08,250 MWh of battery storage along with 18,986 MW of pumped storage hydropower (PSH) by FY30[37] (CEA 2023b). CEA has also published the national transmission investment plan, which estimates that 51.5 GW of BESS capacity will be required to transmit 279 GW of wind and solar capacity (CEA 2022c).

Our analysis indicates a 32 GW/128 GWh storage requirement to be installed at the Rajasthan periphery to meet national needs (refer to Case 1). Presently, Rajasthan does not have any deployment of storage systems. However, the state is initiating steps towards meeting the nationally set energy storage obligation (ESO) targets

35 Based on our assessment of thermal operational characteristics data obtained from Rajasthan SLDC.

36 As per CEA standard, coal units need to ramp at 1 per cent per minute, i.e. a 500 MW unit can change its generation by ±5 MW in a minute (CEA 2019a).

37 The current installed capacity of pumped hydro storage is 4,746 MW (CEA 2022b).

(MoP 2022). To meet the mandate of 4 per cent consumption through storage in FY30, Rajasthan must procure close to 7,000 MUs in that year.[38] This will be equivalent to a diurnal BESS capacity of 4.8 GW with 4-hour storage or 2.54 GW-7 hours PSH or a combination of both.

To this end, Rajasthan must provide an environment for early investments in energy storage solutions across various applications and identify the operational models and technologies best suited for the state. In the short term, the state discoms, in consultation with the RE nodal agency, transmission company, and generating companies, could initiate a diverse set of pilot projects using BESS technologies. These projects could be based on different cell chemistries and be deployed at transmission or distribution levels. Such pilots would allow the discoms to study various BESS-use cases like fast ramping services, frequency control, reducing RE curtailment, trading energy from storage on market platforms when surplus, and firming up open access supply. The RE nodal agency must also identify prospective sites for large and off-river PSH projects and conduct due diligence on land, hydrological, and environmental considerations for their development.

c. **Facilitate the use of select hydro-electric plants as balancers**:
Hydro-electric plants are a quicker and cheaper flexible solution, exhibiting faster ramps, minimal start-up time, providing inertial and reactive power support to manage the frequency and voltage in the system (International Energy Agency (IEA) 2021). Grid Controller of India, the national system operator, analysed the potential and mechanisms for using hydroelectric energy for multiple applications at different points in time, such as peaking time, ramping support, ancillary services, and pumped storage hydro (Forum of Load Despatchers (FOLD) 2017). Scheduling hydro as a base generator due to its lower cost restricts the resources for these applications (CEA 2023e). If reservoir-based hydro plants (purely power generation projects) are scheduled optimally, i.e., when the system anticipates high ramping requirements, sudden peaks or high uncertainty, then hydro can be used as a balancer.

Grid India and MoP’s recent roadmap to develop India’s electricity markets proposes a compensation mechanism for valuing hydro as a balancing resource to fit in the existing merit order system (FOLD 2017; MoP 2023b). Rajasthan has a contracted capacity of 1.9 GW hydro plants as of 2022. The government of Rajasthan can collaborate with the central stakeholders to facilitate a study that identifies the candidate hydro plants and a compensation mechanism to compensate for the flexibility services.

38 Considering Rajasthan will consume 133 BU of electricity as per CEA’s 20th Electric Power Survey and will meet the 4 per cent ESO through battery storage systems that will have a roundtrip efficiency at 85 per cent and depth of discharge at 90 per cent.

D. Invest in upgrading grid technologies for better system control and enhanced communication abilities:

Transmission utility and system operator would need to ensure implementation of grid-asset monitoring systems such as sensors and advanced analytics that generate high-resolution data on grid conditions, system-integrity protection schemes and digitalisation of substations to ensure grid reliability and flexibility. Modern hardware and software systems for complete visibility of real-time RE generation from every state plant will help improve RE forecasting accuracy. Finally, technology solutions that provide reactive power support will need enhanced focus while planning for strengthening the state network. The state grid code, last notified in 2008, may introduce provisions around providing grid support and voltage and harmonics management in line with the recently notified central grid code.

E. Enhancing demand-side flexibility by promoting distributed resources and supporting regulatory frameworks.

Demand-side management programs enable consumers to adjust their electricity consumption patterns in response to price signals or grid conditions. By reducing electricity demand during peak periods or increasing it during times of excess generation, demand-side flexibility helps balance the system and reduce the need for additional generation capacity. In Rajasthan, there is an opportunity to considerably shift agricultural demand to daytime and utilise decentralised solar power to meet the same. This will help control transmission losses arising due to low reactive power support. Influencing demand through time of day (ToD) tariff is a prevalent option amongst states, but for limited consumer categories. In Rajasthan, ToD tariffs only apply to some categories of HT and EHT consumers. The state discoms must assess the effectiveness of the current ToD tariff regime to align it with evolving energy use patterns. In parallel, the electricity regulator must notify demand-side management regulations to unlock the potential of flexible demand-side resources.

4. COST-EFFECTIVE OPERATION OF THE STATE'S THERMAL FLEET

So far, we have discussed the technical aspects of integrating 90 GW of solar and wind energy capacity in Rajasthan's electricity grid. But how are the power procurement costs likely to be affected? Power procurement costs are an important question because, in FY22, Rajasthan's discoms spent an average of INR 0.06 more to supply an electricity unit (kWh) to consumers than the revenue they recovered for it, leading to a total revenue deficit of INR 472 crore (PFC 2023b).[39] Of discoms' total allowed expenditure of INR 57,675 crore in FY22, power procurement costs comprised the single largest share at 70 per cent and about 60 per cent of the disallowed costs were related to power procurement (RERC 2023a).[40] Therefore, this section proposes short-to-medium-term levers for optimising power procurement costs. This would help discoms close the revenue gap, reduce working capital requirements and associated carrying costs, and improve discoms' overall financial position.

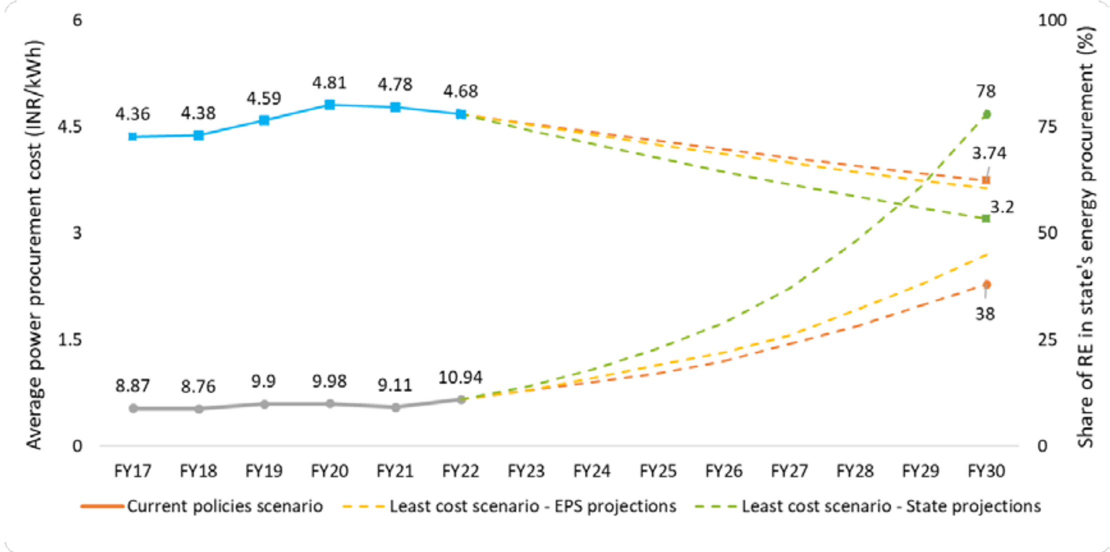
Procuring higher shares of the annual energy requirement from RE sources is likely to be the most effective lever to mitigate future escalation in power procurement costs. For example, in the 2030 horizon, if the share of RE in the state's energy procurement rises from 38 per cent to 78 per cent, the average power procurement cost (APPC) could fall from INR 3.74/kWh to INR 3.20/kWh (Idam Infrastructure 2023) (Figure 4.1).[41] However, simulation studies assume that the thermal fleet will operate cost-efficiently while providing the flexibility required to integrate RE. We focus on how Rajasthan can achieve this to ensure that RE's benefits in terms of lower APPC are realised.

[39] Gap computed on energy sold basis, whereas revenue deficit is on accrual basis.

[40] Power procurement costs include transmission and SLDC charges.

[41] In Rajasthan, APPC includes payments to power generators under long- and short-term contracts, payments to traders (including trading margins), net expenses for purchases through power exchanges, banking-related charges, settlements against unscheduled interchange, and transmission charges.

Figure 4.1: Integrating renewable energy is the most effective lever to reduce APPC



Source: PFC's reports on the performance of power utilities FY17-FY22 and Idam Infrastructure (2023)

Like most other states, Rajasthan depends on long-term contracts for most of its bulk power procurement. In FY22, only seven per cent of the total energy purchased was from short-term sources (power exchanges, traders and Unscheduled Interchange). The state has a contracted electricity generation capacity of 23,482 MW against a peak load of about 15,000 MW in FY22, of which almost 70 per cent is wholly or jointly owned by Rajasthan Rajya Vidyut Utpadan Nigam (RRVUN) (Table 4.1).[42] The remaining capacity is evenly split between central (GoI) and private companies.

Table 4.1: State-owned capacity forms the largest share of Rajasthan's long-term contract portfolio

Sector	Contracted capacity (MW)	Energy procured in FY22 (MUs)	Energy-weighted average total cost (INR/kWh)
State + shared	16,571	44,802	4.27
Central	3,048	13,860	3.43
Private	3,863	22,613	4.09

Source: Discoms' true-up petitions for FY22

The state-owned thermal capacity is concentrated in a few large plants, while the centrally-owned thermal capacity is more fragmented (Figure 4.2). With capacities of 1,000-1,500 MW, seven out of eight state-owned thermal plants account for nearly a third of the discoms' total tied-up long-term capacity. These seven plants fall within a

[42] The total contracted generation capacity includes 6.7 GW of wind and solar capacity, which operates at roughly 30 per cent and 20 per cent capacity utilisation factors, respectively.

narrow range of per kWh cost of energy supplied (INR 4 - 5.6/kWh). On the other hand, 17 centrally-owned thermal power stations form less than 7 per cent of the total contracted capacity, and their cost falls in the broader range of INR 2.2 - 5.8/kWh.

Figure 4.2: Rajasthan's state-owned thermal capacity is concentrated in a few large power stations

Source: Discoms' true-up petitions for FY22

Apart from procurement under long-term contracts, in FY22, Rajasthan procured energy under trading agreements at an average cost of INR 3.5/kWh and sold and purchased energy on the power exchange at average rates of INR 3.49/kWh and INR 4.64/kWh, respectively. Solar plants represented one of the state's largest and cheapest energy sources at an average cost of INR 3.1/kWh, while at INR 5.1/kWh, wind energy fell marginally above the state's average. Overall, at INR 4.68/kWh, Rajasthan's APPC in FY22 was just under the national average of INR 4.77/kWh and lowest among other large states like Karnataka (INR 5.62/kWh), Uttar Pradesh (INR 5.08/kWh), Gujarat (INR 4.98/kWh), Maharashtra (INR 4.97/kWh), and Tamil Nadu (INR 4.96/kWh) (PFC 2023b).

For our analysis, we focus on 8 thermal plants that comprised over 40 per cent of the state's total contracted capacity and about half of the energy purchased in FY22 (Table 4.2). The plants range from 1,000-1,500 MW capacities, 110-660 MW unit sizes, and 2-35 years of operational age.

Table 4.2: Eight thermal power plants comprise 42 per cent of Rajasthan's total contracted capacity

Plant name	Installed/contracted capacity (MW)	Ownership	Company	Commercial date of operation
Suratgarh Thermal Power Plant (TPP)	1,500 (6x250)	State	RRVUN	Unit 1 - 1999 Unit 2 - 2000 Unit 3 & 4 - 2002 Unit 5 - 2003 Unit 6 - 2009
Kawai Super Critical TPP	1,320 (2x660)	Private	Adani Power	Unit 1 - 2013 Unit 2 - 2014
Chhabra Super Critical TPP	1,320 (2x660)	State	RRVUN	Unit 1 - 2018 Unit 2 - 2019
Suratgarh Super Critical TPP	1,320 (2x660)	State	RRVUN	Unit 5 - 2020 Unit 6 - 2021
Kota TPP	1,240 (2x110, 3x210, 2x195)	State	RRVUN	Unit 1 & 2 - 1983 Unit 3 - 1988 Unit 4 - 1989 Unit 5 - 1994 Unit 6 - 2003 Unit 7 - 2009
Kalisindh TPP	1,200 (2x660)	State	RRVUN	Unit 1 - 2014 Unit 2 - 2015
Jalipa Kapurdhi (Rajwest) TPP	1,080 (8x135)	Private	JSW Energy	Unit 1 - 2010 Unit 2 - 2011 Unit 3 - 2013
Chhabra TPP	1,000 (4x250)	State	RRVUN	Unit 1 - 2009 Unit 2 - 2010 Unit 3 - 2013 Unit 4 - 2014

Source: Discoms' true-up petitions for FY22

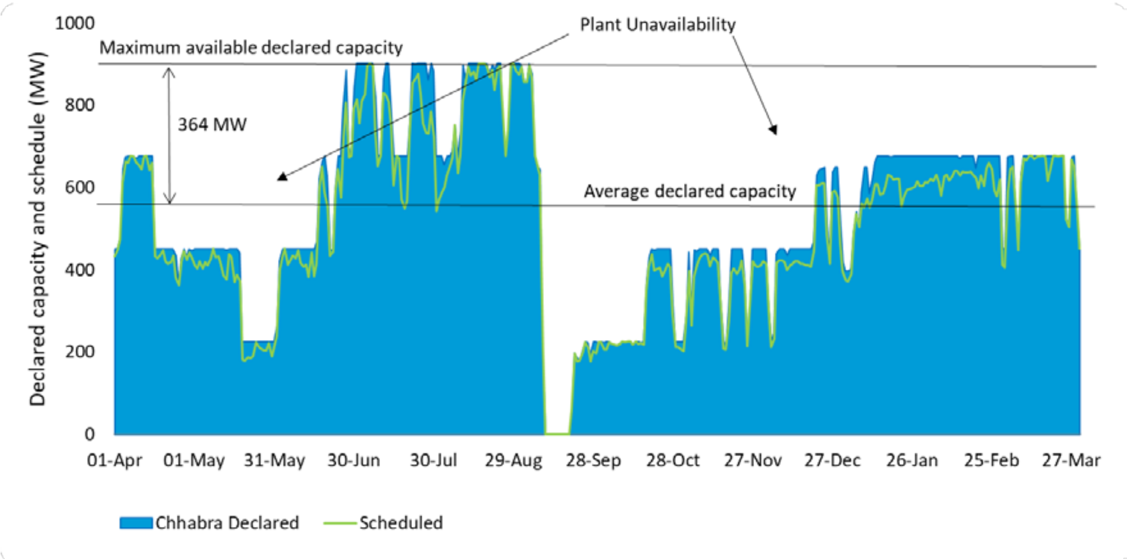
We analyse three aspects of coal fleet operation that can help optimise the cost of power: 1) Availability of power plants to provide electricity, 2) economically efficient scheduling of available plants, and 3) accurately forecasting demand.

4.1 Maintaining high availability of existing state-owned thermal plants

Declared capacity (DC) or availability of thermal plants affects the discoms' power procurement costs in two ways: through capacity payments and the need to procure energy from short-term sources. Capacity payments are made to thermal plants for being available to supply energy and are based on actual DC. In case of non-availability or low DC of plants, discoms may have to procure energy from alternative sources, such as the power exchange. Non-availability of dispatchable energy (thermal plants in the case of Rajasthan) can also make it more difficult to meet demand while utilising higher volumes of variable RE.

We observed that the DC of the six state-owned plants in FY22 ranged from 31.7 per cent for Suratgarh TPP to 68.3 per cent for Kalisindh TPP, well below the target availability of 83 per cent (RERC 2019).[43] Figure 4.3 shows an example of how plant DC varied over FY22.

Figure 4.3: Average DC of thermal plants was much lower than their maximum DC in FY22



Source: Authors' analysis using data from Rajasthan SLDC for FY22

The average DC of Chhabra TPP and Chhabra Super Critical TPP was 59 per cent and 56 per cent of their actual maximum DC, respectively.[44] The gap between the average DC and the maximum DC indicates room for improvement in availability to supply energy.[45] The discoms have also highlighted that the weighted average availability of state-owned plants in FY20 to FY22 was 66 per cent, and during FY23, until February

[43] Regulation 45 of the cited regulations.

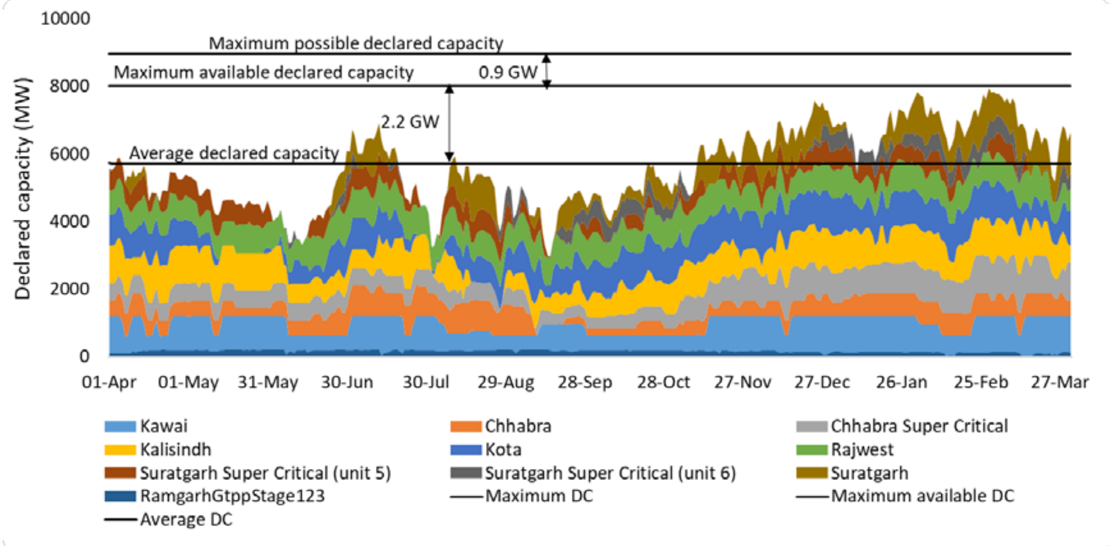
[44] Similar plots for the other plants can be found in Annexure IV.

[45] Here we note that it is infeasible to maintain the maximum declared availability throughout the year due to annual maintenance requirements and unexpected outages.

2023, it was 61 per cent (RERC 2023a).[46] On the other hand, the private plants (Kawai TPP and Rajwest TPP) maintained an average DC higher than 75 per cent.

In FY22, about 900 MW of additional peak capacity could have been available if the DC of selected plants was equivalent to their maximum possible DC (Figure 4.4).[47] This directly avoids investments in new generation capacity to meet the peak demand. Further, up to 17,000 MUs of additional energy could be available if the selected plants met the target availability of 83 per cent, equivalent to about 15 per cent of the state's total energy procurement. Hence, higher availability of the existing fleet could lead to avoided capacity investments to reliably meet demand and reduce dependence on short-term or other costlier sources to meet the energy requirement.

Figure 4.4: Higher DC could improve peak generation availability by almost 1 GW



Source: Authors' analysis using data from Rajasthan SLDC for FY22

Note: The maximum possible declared capacity is the cumulative plant wise installed capacity minus auxiliary consumption.

As we can see from Table 4.2, TPPs comprise multiple units. DC represents the availability of the operational units to supply energy. If individual units are under an outage and unavailable to supply energy, it significantly and adversely affects plant-level DC. We discuss the reasons for outages in the next section.

Reasons for capacity outages

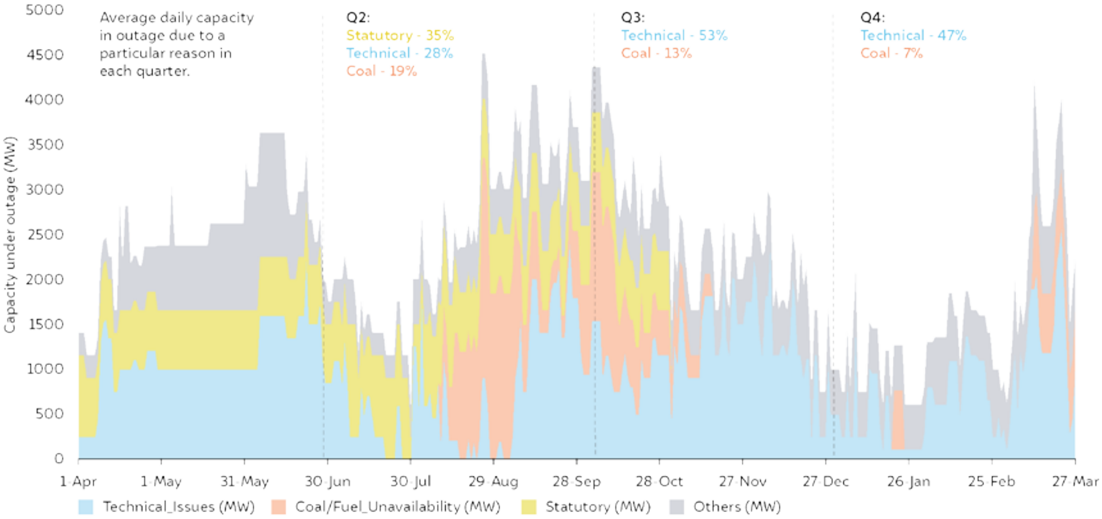
Technical issues, statutory outages or planned annual maintenance, and coal unavailability were the largest reasons for outages in Rajasthan's state-owned plants throughout FY22 (Figure 4.5). Statutory outages are a major reason only during the first half of the fiscal year (April-September), demonstrating a clear effort by RRVUN

46 Paragraph 5.168 on page no. 182 of 287 of the cited order.

47 Maximum possible availability is estimated as the difference of installed capacity and 10 per cent auxiliary consumption.

to carry out annual maintenance ahead of the state's annual peak demand season. However, in the second half of the year (October-March), on average, nearly half the capacity in outage was due to technical reasons, which amounts to an average of 1,020 MW in outage daily for six months. Technical issues include boiler, turbine and generator-related issues.[48] An average of 20 per cent of capacity was under outage due to coal unavailability during the monsoon season (July-September). However, coal unavailability was not a major reason for outages during the rest of the year, indicating that RRVUN could maintain adequate coal stocks at its plants.

Figure 4.5: Technical issues and statutory outages in state-owned plants were the largest reasons for outages in FY22



Source: Authors' analysis using CEA's daily operational monitoring reports

Notes: 1) The figure shows RRVUN-owned thermal capacity in outage daily in FY22. 2) Technical issues include boiler, boiler auxiliary, turbine, turbine auxiliary, and generator issues. "Others" includes issues related to ash or coal handling, balance of payments, water unavailability, grid conditions, and switchyard/electrical issues.

RRVUN must improve operation and maintenance (O&M) practices and reduce the incidence of technical issues to enhance the utilisation of the existing thermal fleet. In FY22, RRVUN reported underutilising some plants' O&M expenses allowed under RERC regulations. The generating company claimed INR 203.22 crore, INR 124.78 crore and INR 179.61 crore as O&M expenses for Suratgarh TPP, Kalisindh TPP and Chhabra Super Critical TPP against the allocated INR 324.64 crore, INR 233.74 crore and INR 257.12 crore, respectively (RERC 2023b). Timely payment by the discoms for energy purchases and access to affordable working capital would enable RRVUN to direct financial resources towards enhanced maintenance practices.

RERC must also take steps to enable RRVUN to improve O&M practices, factoring in the actual needs of the power plants. For example, the O&M costs allowed to

48 See Annexure V for details.

RRVUN under state regulations are lower than those allowed to central plants by CERC (Table 4.3). For example, the annual O&M expenses allowed to Suratgarh TPP, Kota TPP and Chhabra TPP, with unit sizes of 250 MW and below, are almost half the O&M expenses allowed to centrally-owned plants of comparable sizes under CERC regulations over FY20-24. These are older plants and may have higher O&M requirements than newer plants with larger unit sizes, such as Suratgarh Super Critical TPP, Chhabra Super Critical TPP and Kalisindh TPP.

Table 4.3: O&M expenses allowed under RERC regulations are lower than under CERC regulations

O&M expenses allowed to generating companies for different unit sizes (INR lakhs/MW)						
	CERC regulations			RERC regulations		
	200/210/250 MW series	600 MW series	Annual escalation	110-250 MW	> 250 MW	Annual escalation
FY15	23.90	14.40	~ 6.3%	16.09	14.48	5.85%
FY16	25.40	15.31		17.03	15.33	
FY17	27.00	16.27		18.03	16.22	
FY18	28.70	17.30		19.08	17.17	
FY19	30.51	18.38		20.20	18.18	
FY20	32.96	20.26	~ 3.5%	20.20	18.18	3.51%
FY21	34.12	20.97		20.91	18.82	
FY22	35.31	21.71		21.64	19.48	
FY23	36.56	22.47		22.40	20.16	
FY24	37.84	23.26		23.19	20.87	

Source: Authors' analysis based on CERC (Terms and Conditions of Tariff) Regulations, 2014 & 2019; RERC (Terms and Conditions for Determination of Tariff) Regulations, 2014 & 2019

The second aspect of cost-optimal utilisation of the thermal fleet is the efficient scheduling of the available resources. We will discuss this in the next section.

4.2 Adhering to least-cost energy scheduling practices

The available thermal plants must be scheduled based on the 'merit order dispatch' (MoD), i.e., the plant with the lowest variable cost (VC) should be utilised to the fullest extent before using the next cheapest plant, and so on until the marginal plant supplies the last unit with the highest VC to serve the demand at the least cost. This section discusses the practices required to minimise deviations from the MoD principle while flexibly operating TPPs.

Our analysis shows that the state largely follows the MoD principle, but there is room for improvement. For example, during the peak demand months of November-March in FY22, scheduled generation from some lower-cost plants, like Kalisindh TPP and Kawai TPP, deviated by more than 100 MW from their respective DC (Table 4.4). Smaller deviations (> 50 MW) occurred more frequently across all plants, especially Kawai TPP, Kota TPP, Kalisindh TPP, and Suratgarh TPP.

Table 4.4: Large and lower-cost plants were frequently under-scheduled

	Energy-weighted Variable cost	Maximum deviation	Percentage of days in a month when scheduled generation deviated from DC							
			By > 100 MW				By > 50MW			
TPP	**(INR/ MWh)**	**(MW)**	**Nov**	**Dec**	**Jan**	**Feb**	**Nov**	**Dec**	**Jan**	**Feb**
Suratgarh	4,020	660*	10	20	7	32	57	93	23	79
Kawai	2,590	336	33	43	70	7	70	93	97	39
Suratgarh Super Critical (unit 5)	3,270	174	0	13	13	0	0	67	27	7
Kota	3,380	208	43	13	53	43	93	100	100	100
Suratgarh Super Critical (unit 6)	3,220	625*	0	0	0	0	0	7	7	4
Kalisindh	3,020	318	27	77	77	46	67	97	100	86
Chhabra	3,260	169	0	0	3	0	13	7	67	43
Rajwest	2,550	172	3	0	0	0	27	13	43	18
Chhabra Super Critical	2,630	119	0	0	0	4	10	37	3	21

Source: Authors' analysis using data from Rajasthan SLDC for FY22

Note: *The maximum deviations observed were for Suratgarh (660 MW, only for one day) and Suratgarh Super Critical unit-6 (625 MW during 4-6 October 2021). Variable cost is the weighted average cost of the plant.

The observed deviations of scheduled energy relative to DC could be due to many reasons: higher than expected RE availability, lower than anticipated demand, grid congestion, or contractual obligations to provide minimum schedules to certain plants. However, to the extent that the deviations are observed during the peak demand and lean RE season, they may represent opportunities for fuller utilisation of lower-cost plants. For example, the full availability and utilisation of Chhabra Super Critical

TPP, Kawai TPP and Rajwest TPP could have helped save nearly INR 500 crore by replacing nearly 3,400 MUs of energy procured from Suratgarh TPP in FY22 (Table 4.5).

Table 4.5: Plant-wise saving by reduction of shortfall in FY 2022

Plant name	Variable cost (INR/ MWh)	Additional energy at 83% availability (MUs)	Generation utilised to replace marginal plant (MUs)	Potential savings (INR crore)
Rajwest TPP	2,550	435	435	64
Kawai TPP	2,590	852	852	122
Chhabra Super Critical TPP	2,630	2,810	2,149	299
Total savings				**485**

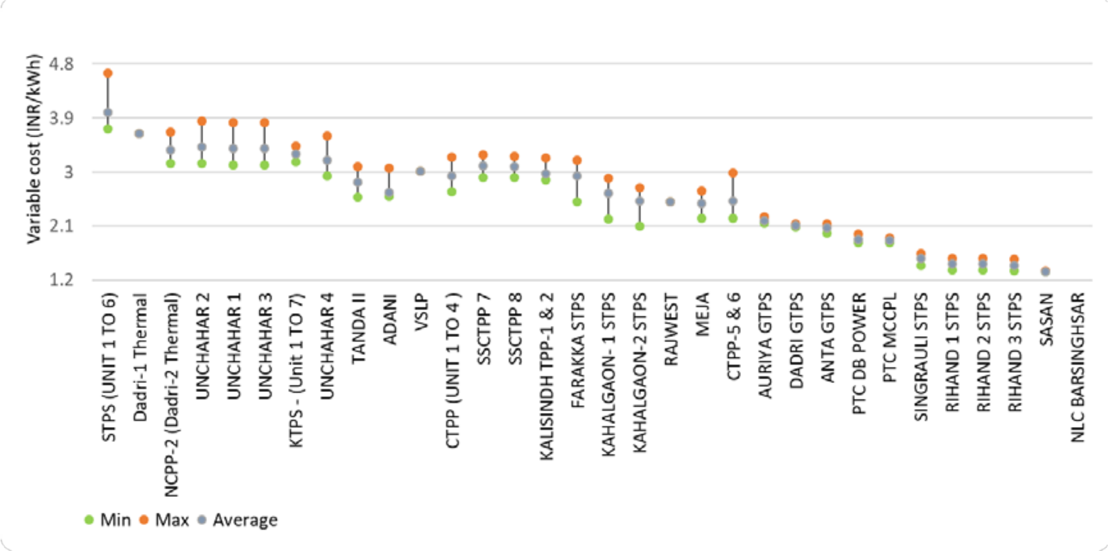
Source: Authors' analysis using data from Rajasthan SLDC

Notes: 1) We assume that in the absence of energy from the above plants, discoms would have procured energy from alternative sources at a rate equal to that of the marginal plants in the merit order. 2) Based on the VC-weighted average cost of the plant, the marginal plant was Suratgarh TPP. 3) Additional energy at 83% availability (MUs) = 365 X 24 X 83% X Maximum available DC.

Rajasthan Urja Vikas Nigam Limited (RUVNL), the state-owned energy trader, currently determines the energy to be procured from each plant on behalf of the discoms based on a weekly MoD stack, i.e., the stack of plants' VC in ascending order. Data on monthly plant-level energy supplied and notified VC shows that scheduling largely followed the MoD principle in FY22. However, the method of calculating the VC suffers from some shortcomings:

1. **Non-inclusion of inter-state transmission charges:** The VC of state-owned plants is estimated as the sum of the ex-bus cost of energy generation (the energy charge rate, ECR) and the intra-state transmission charges. However, the VC of centrally-owned plants does not include inter-state transmission charges, possibly leading to a lower VC and a higher priority in the MoD stack relative to state-owned plants. This may have also led to systematically lower utilisation of state-owned plants.
2. **Inconsistent ECR reporting timelines:** ECR depends on factors such as coal availability, coal quality, plant load factor, etc., which causes the VC to vary throughout the year. For example, Suratgarh TPP's VC varied from INR 3.7-4.7/kWh in FY22 (Figure 4.6). Current practices require RRVUN to provide data on the ECR of state-owned plants to discoms 45-55 days after the month of actual generation. For generation in April, the data is provided 70 days after the completion of the month. On the other hand, centrally- and privately-owned plants provide bills after 10-15 days (RERC 2022). Procuring energy from state-owned plants based on 2-3 month-old VC could lead to higher costs since the prospective MoD would not reflect the most recent generation cost.

Figure 4.6: ECR must be reported more frequently to capture the impact of ECR on MoD



Source: Authors' analysis of the weekly MoD data published on the discoms' website for FY22

Note: Dholpur TPP (natural gas-based) is excluded from the chart above due to high VC variations.

As per our analysis, discoms had to shell out almost INR 370 crore in additional power procurement costs in FY22 due to variations in VC of seven plants (state- and centrally-owned)(Table 4.6).[49]

Table 4.6: VC variations led to additional power purchase costs for discoms in FY22

S. No.	Name of TPP	Approved generation (MUs)	Approved VC (INR/ kWh)	Total actual generation (MUs)	Total cost at approved VC (INR crore) (A)	Total cost at actual VC (INR crore) (B)	Weighted average VC for all quarters (INR/kWh)	Variation in total VC (INR crore) (A-B)
1	**Kota**	4,852	3.39	6,277	2,128	2,116	3.38	12
2	**Suratgarh Super Critical**	2,958	2.74	2,015	552	658	3.27	-106
3	**Chhabra**	7,736	2.18	5,539	1,207	1,461	2.63	-253
4	**CGPL**	2,140	1.89	413	78	82	2	-4
5	**Farakka**	49	2.81	46	13	14	3.07	-1
6	**Kahalgaon- 1**	129	2.25	147	33	37	2.53	-4
7	**Kahalgaon-2**	497	2.12	651	138	155	2.39	-17
	Total				**4,149**	**4,524**		**-374**

Source: Authors' analysis based on data provided by discoms for quarterly fuel surcharge adjustment calculations

[49] The analysis is based on the VCs as per the weekly MoD stack issued by RUVNL and the quarterly VCs and the net generation used to calculate the quarterly fuel surcharge adjustment. The impact of inter-state transmission losses and charges could not be included due to unavailability of data.

3. **Inadequate operating guidelines for power plants:** In 2018, RUVNL constituted a committee to frame a methodology for preparing the MoD stack by considering the fuel surcharge adjustment (FSA), a mechanism to adjust actual fuel costs in future VC. However, the committee's recommendations did not cover some crucial grid operation aspects affecting the FSA. These include operating parameters such as the plants' technical minimum, reserve margins of TPPs connected to the state transmission system, and the conditions under which plants shall be put into Reserve Shut Down (RSD).

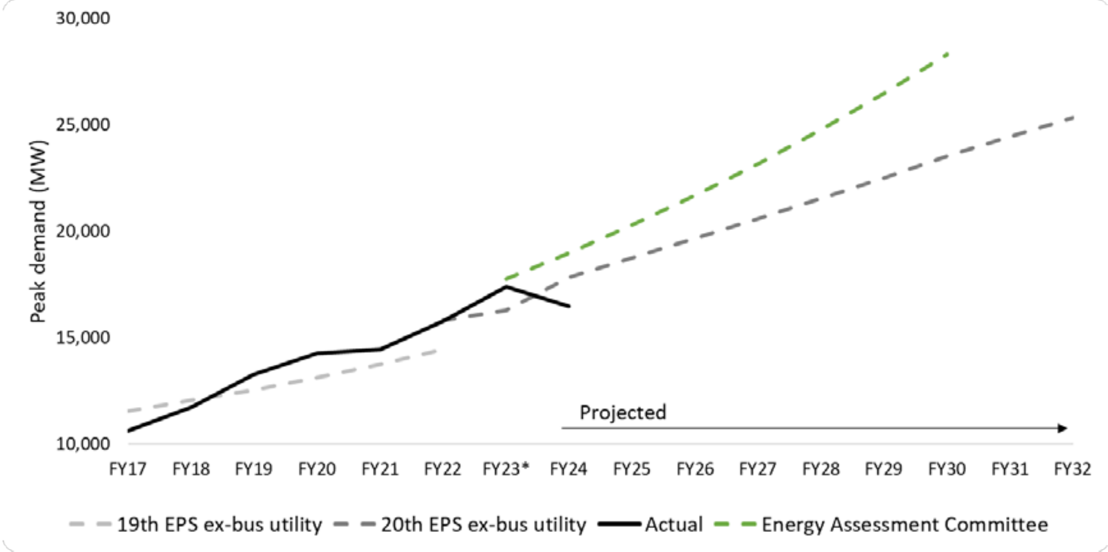
As TPPs are operated at lower PLFs and are ramped more frequently to provide flexibility to the grid, variations in VC are likely to become larger. RERC must notify a methodology for estimating the VC and drawing up the MoD stack to ensure transparency in the magnitude of and reasons for such variations and to ensure that the least-cost dispatch is followed. The methodology must incorporate CERC's regulations on usage-based inter-state transmission charges (CERC 2020) and guidelines on the treatment of FSA. The methodology may be notified through a new MoD regulation, such as done by the Maharashtra and Uttar Pradesh Electricity Regulatory Commissions or by amending the Rajasthan State Grid Code or the Multi-Year Tariff Regulations.[50]

4.3 Upgrading demand forecasting methods for higher accuracy

Demand forecasts are an essential input, combined with information on the availability and costs of generation sources, to power procurement operations. Rajasthan's discoms and RUVNL sign contracts for power supply based on the state's Energy Assessment Committee (EAC)'s projections but the actual peak demand may deviate from these forecasts and CEA's EPS projections (Figure 4.7).

50 See Annexure VI for details on suggested guidelines.

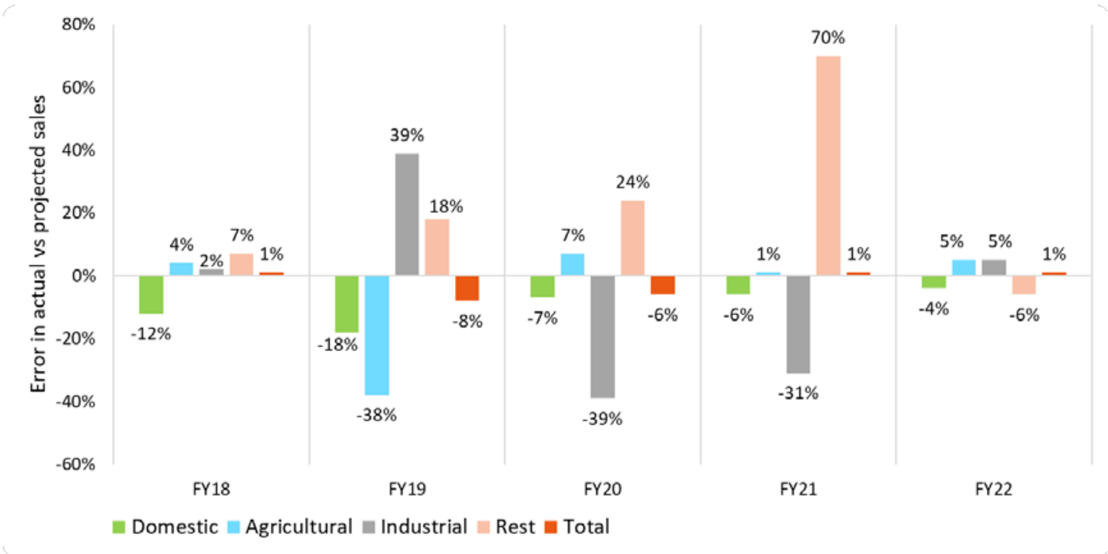
Figure 4.7: Actual peak demand has historically deviated from estimated peak demand



Source: Authors' analysis based on discoms' petitions; CEA's 20th EPS (2022a); RERC (2023c)
Note: *The EAC data point for FY23 is a projection.

While the total energy demand has not deviated much from year-ahead expectations, consumer segment-wise energy demand has heavily diverged from forecasts since at least FY18 (Figure 4.8).

Figure 4.8: Consumer segment-wise energy demand has historically diverged significantly from forecasts



Source: Authors' analysis based on discoms' true-up petitions, RERC ARR, and tariff orders for FY18-FY22

Future uncertainty in the energy and peak demand would be driven by higher penetration of behind-the-meter technologies such as solar rooftop units and EVs and behavioural changes such as the adoption of electric cooking. Energy demand is temperature and humidity-dependent due to energy consumption to maintain thermal comfort (Harish et al. 2020; IMD and POSOCO 2022). The agricultural consumption, comprising about 40 per cent of Rajasthan's electricity demand, depends on seasonal rainfall patterns. Rajasthan aims to install 1 GW of solar rooftop capacity and 4 GW of distributed generation capacity by FY25 (GoR 2019a). Almost 3 GW of demand may be served by decentralised RE installed under the KUSUM scheme by 2030.[51] In such a scenario, compounded annual growth rate (CAGR)-based projections and traditional statistical models used by discoms may not accurately estimate demand (Patankar et al. 2023). Recognising this trend, discoms and RUVNL must adopt CEA's updated guidelines on demand forecasting (Box 4.1) (CEA 2023c).

Box 4.1: Key highlights of CEA Draft on Guidelines for Medium and Long-Term Power Demand Forecast

- Demand estimations for the medium-term (1-5 years) and long-term (5-10 years) should be prepared, reviewed and updated on a yearly basis.
- Estimations should be on the basis of the base year, i.e., the two-year preceding the year for which the forecasting exercise is being carried out.
- Estimation should be done at least at the discom-level but can be carried out at the zonal-, circle-, district-, sub-station- or feeder/transformer levels in case more granular data is available. In addition to year-wise forecasts, monthly/daily/hourly/time-block-wise forecasts should also be carried out on the basis of the availability of granular-level data.
- Results of the Partial End Use Method (PEUM) should be compared with other methods (preferably the Econometric Method), and the impacts of emerging technologies such as electric cooking, EVs, etc. should be factored in.
- Forecasts should be done for 'optimistic', 'business-as-usual' and 'pessimistic' scenarios.

On an operational timescale, uncertain net demand[52] can cause deviations of energy scheduled from TPPs from their DC. Errors in demand forecasts can lead to deviations from MoD-based energy procurement and foregone opportunities to sell surplus energy. Stakeholder consultations suggest that RUVNL currently operates with a day-ahead forecasting accuracy of 80-90 per cent, indicating some scope for enhancement. Discoms are piloting various statistical and deep learning tools using 15-minute load data to achieve higher accuracy in demand forecasts on operational

[51] Based on the Saur Krishi Ajivika Yojana (SKAY) portal (GoR n.d.).

[52] Net demand is the difference of the total demand to be served and available weather-dependent RE.

timescales, such as day-ahead and week-ahead (REC et al. 2022).[53] These methods combine weather events, maintenance schedules, consumer profiles, holidays, etc., with granular historical load data to forecast demand.

Demand forecasting exercises traditionally conducted by the CEA, discoms or other power system entities suffer from some critical shortcomings. These include the unavailability of granular and reliable input data, dependence on assumed parameters such as network losses, absence of integration with diverse datasets such as socio-economic and weather trends, and non-assessment of latent demand (World Energy Council India, n.d.). However, using new methodologies that promise higher accuracy requires good-quality data on diverse metrics and high temporal and spatial granularity.

With the rollout of consumer and upstream smart meters, including under the Revamped Distribution Sector Scheme (RDSS), discoms must utilise demand data to improve forecasting accuracy using updated methods. Socio-economic and demographic data must be collected through periodic consumer surveys to get detailed information on adoption trends of energy-efficient technologies and new appliances for cooling, cooking, etc. The SLDC must also assist the EAC in using the weather data from the India Meteorological Department's Weather Power Portal to incorporate the impact of weather events on demand. Rajasthan IT Vidyut Company may be tasked with assisting RUVNL with conducting forecasting exercises.

4.4 Key recommendations for cost-effective operation of the state's thermal fleet

Based on the presented analysis, we provide recommendations to help operate the thermal fleet cost-efficiently even as more RE is integrated into the state's power system.

1. **Notify an MoD regulation**: The MoD regulation should clarify the methodology to compute variable costs of thermal power plants, including the treatment of fuel surcharge, based on which the MoD stack is prepared. The regulation will bring transparency in the variations in variable costs of thermal power plants and their reasons, based on which an efficient dispatch can be followed every month. This is especially critical as higher shares of RE and variable demand bring increased uncertainty to dispatch schedules.
2. **Ensure higher schedules for low-cost plants when they are available**: As observed, there are many instances where the schedules provided to cheaper plants are lower than their availability. RRVUN should work with generating

53 See Annexure VII for details.

companies and discoms to ascertain the reasons for such under-scheduling and take corrective action. With higher shares of RE and uncertain demand, there is a higher risk of uncertainty in the schedules of existing low-cost plants. Optimising the schedules will be critical to continued adherence to the most efficient MoD and maintaining low APPC.

3. **Improve maintenance practices and retrofit select thermal plants for higher flexibility**: The existing trend of forced outages may be due to several reasons. However, with higher shares of RE, thermal plants will increasingly be expected to provide ramping capability and flexible operation. Improving maintenance practices to limit forced outages and retrofitting plants to allow operation at a lower technical minimum will help the continued utilisation of low-cost firm energy to meet demand with higher shares of RE cost-effectively.

4. **Collect detailed demand data to improve the accuracy of demand forecasting**: With higher penetration of consumer appliances, behind-the-meter technologies such as solar rooftop units and EVs, and higher shares of weather-dependent generation, better quality data should be maintained, and computational techniques to accurately forecast impacts of variables such as weather on demand and generation should be employed. Higher accuracy in demand and generation forecasts can help cost-optimally schedule the available energy generation sources.

5. FINANCIALLY HEALTHY DISCOMS AS ENABLERS OF ENERGY TRANSITION

Discoms have a critical role in the state's energy transition and in fulfilling the state's commitment to clean energy targets. As the critical link between the upstream and last-mile consumers, discoms' financial health is vital to the financial sustainability of the entire value chain. This is why high off-taker risk[54] is the most important barrier to clean energy investments in Indian states, which in turn is linked to discoms' poor credit rating and delays in payments to generating companies, among other aspects (Gandhi et al. 2022).

In Rajasthan, three public discoms and a few distribution franchisees provide electricity services to ~1.5 crore consumers across 33 districts. These include Jaipur Vidyut Vitran Nigam Limited (JVVNL), Ajmer Vidyut Vitran Nigam Limited (AVVNL) and Jodhpur Vidyut Vitran Nigam Limited (JdVVNL). Despite some recent improvements, the credit ratings of AVVNL, JVVNL and JdVVNL were B, B- and C, respectively (PFC 2023a).

Further, the average days for generating company payment for state discoms stood at 144 in FY22, more than thrice the limit of 45 days power producers give to the discoms to clear their bills (PFC 2023b). In fact, in 2020, delays in payment by Rajasthan discoms to RE developers were significantly higher than those to conventional power plants (Sharma 2020). However, under strict norms of recently notified Electricity (Late Payment Surcharge and Related Matters) Rules, 2022 (LPS rules), it is expected that the average days payable to generating companies of Rajasthan discoms will come down even while they have had the fourth highest (but reduced) balance legacy dues of INR 8,452 crore among all states as of 24 July 2023 (GoI 2022; MoP 2023d).[55]

Addressing these factors would be critical to deal with the off-taker risks and improve the state discoms' ability to procure affordable and clean energy to serve the state's population, invest in network improvement and augmentation for quality and reliable power supply, and meet their RPO obligations by 2030.

In this chapter, we present the financial health of Rajasthan discoms and discuss the factors underlying their poor credit ratings. We also present short-medium-term

[54] Off-taker risk is the risk of breach of contractual obligation (i.e. to pay for RE) by the off-taker (discoms in this case).

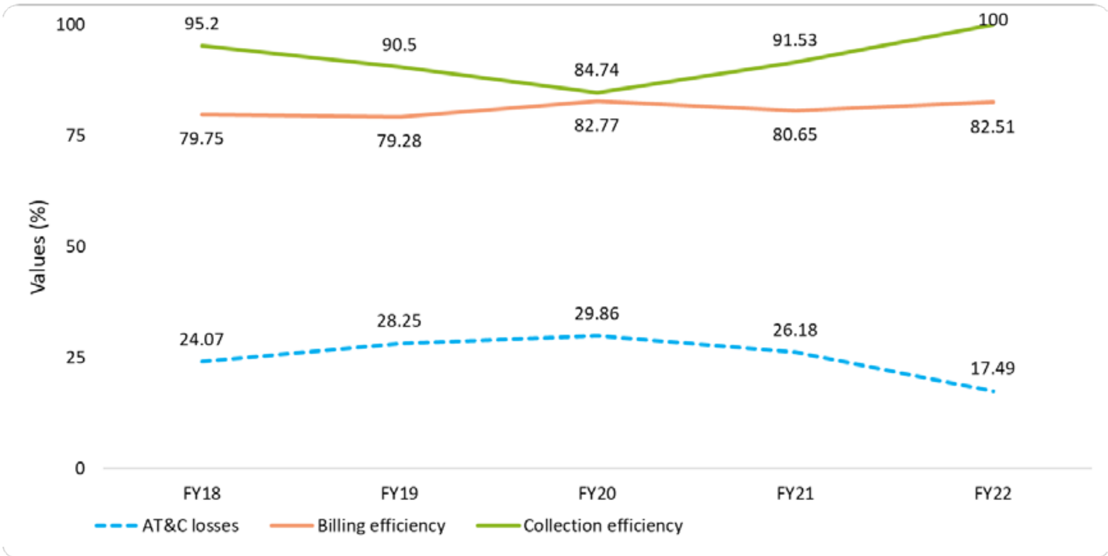
[55] Rules provide for regulation of power access to discoms who default in making payments to generating companies 2.5 months post the bill presentation. Over dues of discoms to generating companies prior to the notification of these rules shall be liquidated through Equated Monthly Instalment (EMI).

interventions that could boost discoms' ratings, dissipate their regulatory assets, improve discoms' operational efficiency and be instrumental in re-pivoting the state discoms to become enablers of the energy transition.

5.1 Overview of the financial health of Rajasthan discoms in FY22

Aggregate Technical and Commercial (AT&C) loss is a common metric used to assess the financial performance of discoms in India and elsewhere.[56] After a period of rising losses, AT&C losses of Rajasthan discoms dropped significantly between FY20 and FY22, from 29.9 per cent to 17.5 per cent (Figure 5.1).[57] This historic improvement in discom performance is mainly driven by the rise in collection efficiency,[58] which is linked to the subsidies received and booked. However, billing efficiency[59] has improved only marginally. Jaipur and Jodhpur discoms, which have lower credit ratings, are the ones with multiple circles with high AT&C losses (>20 per cent) and require targeted efforts to improve billing efficiency (Figure 5.2).

Figure 5.1: Rajasthan discoms have significantly lowered their AT&C losses, which can be further reduced by improving billing efficiency



Source: Authors' analysis based on PFC reports

Note: Blue borders indicate area served by Jodhpur discom; Brown indicate Ajmer discom; Red indicates Jaipur discoms

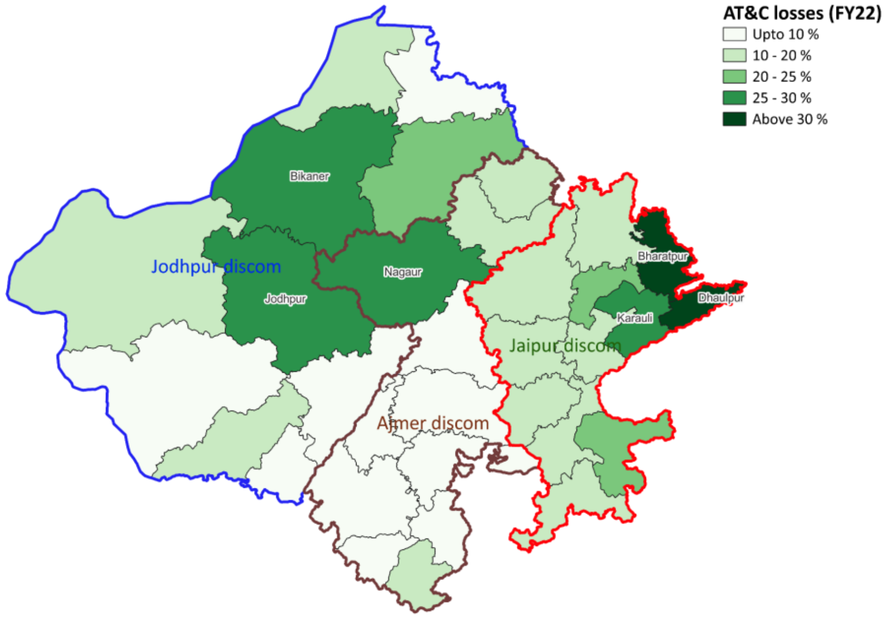
56 AT&C losses are measured as the difference between the energy input and the energy realized, divided by the energy input. Alternatively, AT&C losses are a reflection of gaps in billing and collection efficiency of discoms.

57 AT&C losses of Distribution Franchises of Kota, Bharatpur, Ajmer, and Bikaner in FY21 were 25.09 per cent, 18.93 per cent, 10.20 per cent and 16.82 percent, respectively as per discoms' data obtained through CMRETAC.

58 Collection efficiency is the amount collected from consumers with respect to the amount billed to them in a month.

59 Billing efficiency is the proportion of the input energy that has been billed to the consumers. It includes both metered and unmetered sales.

Figure 5.2: Jaipur and Jodhpur discoms have multiple circles with high AT&C losses



Source: Authors' compilation based on discoms' tariff petitions

While the year-on-year losses are declining, state discoms are saddled with two critical challenges.

- **High accumulated losses:** At the end of FY22, the accumulated losses of the Rajasthan discoms amounted to around ~ INR 90,000 crore (Table 5.1). Of the accumulated losses, ~INR 49,000 crore are in the form of an unfunded revenue gap (or regulatory assets).[60] To put these accumulated losses in perspective, Rajasthan alone accounts for over a sixth of the combined losses of all public discoms in India, which stood at INR 5.74 lakh crore in FY22.
- **Low Debt-to-Service Coverage ratio (DSCR):** In FY22, Rajasthan discoms had a debt of ~INR 66,000 crore, which was 111 per cent of the revenue booked (compared to the national median of 50 per cent) (PFC 2023a; 2023b). As a result, state discoms have a precariously low DSCR of 0.91.[61] This implies that discoms have net operating income/cash available to cover only 91per cent of annual debt payments and would need to borrow more. In comparison, the DSCR of discoms in Gujarat, Haryana and Karnataka stood at 6.2, 1.8, and 1.64, respectively, in FY22.

60 Regulatory assets are previously incurred expenditures that have been deferred by the regulator and can be recovered from consumers by regulatory authorities in future through tariff revision.

61 A DSCR of less than 1 denotes a negative cash flow, and the borrower may be unable to cover or pay current debt obligations without drawing on outside sources or borrowing more.

Table 5.1: Rajasthan discoms have accumulated high losses (~INR 90,000 crore)

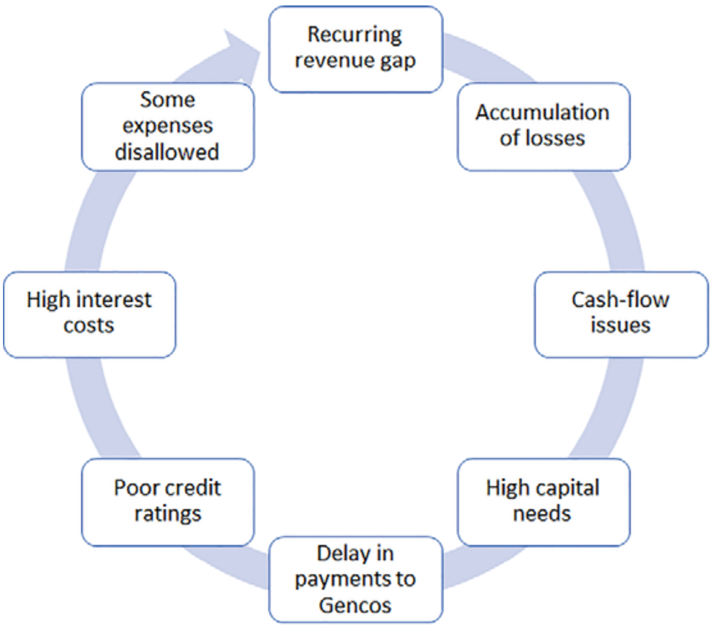
Discom	Losses in INR crore (share of total) As of FY22
AVVNL	27,497 (31%)
JVVNL	32,962 (37%)
JdVVNL	29,097 (32%)
Rajasthan overall	89,556

Source: Authors' analysis based on PFC (PFC 2023b)

5.2 Understanding the vicious cycle of losses, debt and poor credit ratings

Over the years, the recurring revenue gap[62] of Rajasthan's discoms has contributed to high accumulated losses, leading to cash-flow issues, low DSCR, increased reliance on debt and delayed payments to generating companies. Due to cash flow issues, the discoms also rely on high-interest term loans for working capital requirements. With the obligation towards timely payments to generating companies under the LPS Rules, the capital needs are bound to increase. These factors contribute to discoms' poor credit ratings and higher interest costs (see section 5.3 for details). In FY22, interest costs borne by state discoms were 13 per cent of total liabilities (much higher than average 8 per cent for other discoms) (PFC 2023a). However, part of these rising interest costs are disallowed by the regulator (along with other expenses linked to operational inefficiencies), thus resulting in the annual revenue gap and reinforcing a vicious cycle (Figure 5.3).

Figure 5.3: Rajasthan's discoms are trapped in a vicious cycle of losses, high debt and poor credit ratings



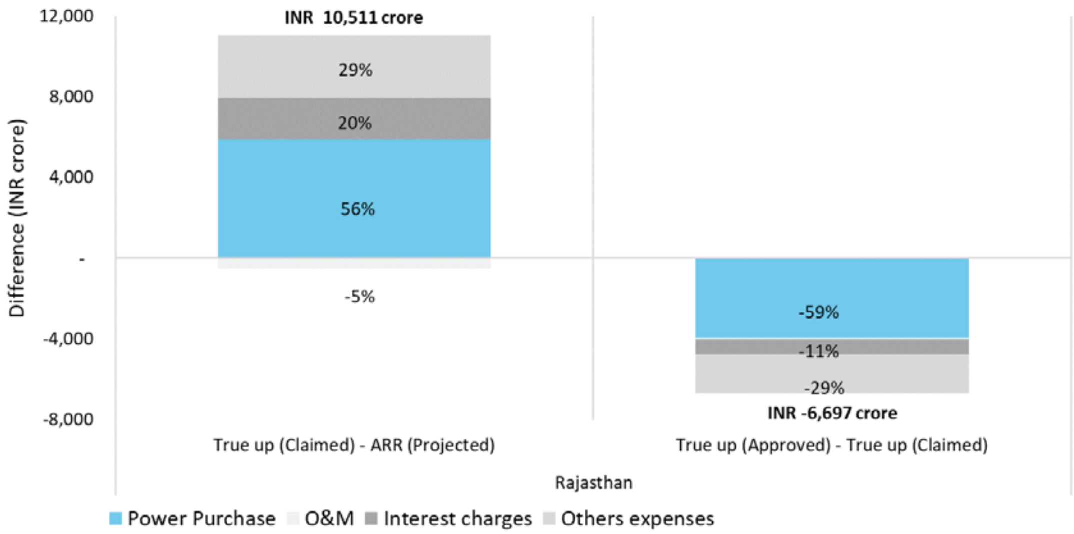
Source: Authors' compilation

[62] Revenue gap is the gap between the cost of supplying power and revenue realised by discoms.

Rajasthan's discoms must address the root causes underpinning the recurring and accumulated losses to break out of this vicious cycle. Among several factors behind recurring losses, the extent of costs disallowed by the regulator is a critical one that adds to the revenue gap. In FY22, Rajasthan discoms made an additional claim of over INR 10,500 crore in their true-up petition, compared to the projections approved during the Annual Revenue Requirement (ARR) exercise. However, RERC disallowed ~INR 6,700 crore of these expenses, of which ~INR 4,000 crore were those of Jodhpur discom alone. Thus, two-thirds of claimed expenses were disallowed, registered as losses in the discoms' balance sheet and directly limited the discoms' ability to recover their expenses.

Figure 5.4 shows that ~60 per cent of the disallowed expenses were against power purchase expenses claimed by discoms, and 11 per cent were against interest costs. The additional (disallowed) claims for power purchase costs are linked to higher-than-allowed distribution losses (inefficiency in metering and billing) and gaps in demand forecasting. For instance, in the case of JdVVNL, the Commission disallowed the sale of 282.40 MUs under the flat rate consumer category under agriculture due to a re-assessment of consumption of agricultural consumers. This reassessment was owing to the presence of almost 50 per cent defective meters. Similarly, RERC has not allowed pass-through of the excess discom losses (beyond 15 per cent), considering it as discoms inefficiencies.

Figure 5.4: RERC disallowed ~INR 6,700 crore of expenses claimed by the state's discoms in FY22



Source: Authors' analysis based on tariff order of FY24

Note: The left panel shows the change in expenses claimed by the discoms in their true-up petition compared to the projections made during the ARR (average revenue required) petition. The right panel shows the change in expenses approved by the regulator during the true-up petition compared to those claimed by the discoms.

Rajasthan discoms need to take concerted steps on three fronts:

- **Undertake measures to boost their credit ratings** to enable access to debt at attractive rates and check the rising interest cost burden,
- **Implement a dissipation schedule for the unfunded revenue gap,** which forms most of the accumulated losses and contributes a high share of the interest cost burden.
- **Improve their billing efficiency** to reduce distribution losses and lower the extent of disallowed costs and revenue gap.

We discuss these in detail in subsequent sections.

5.3 Key levers to improve discoms' credit ratings

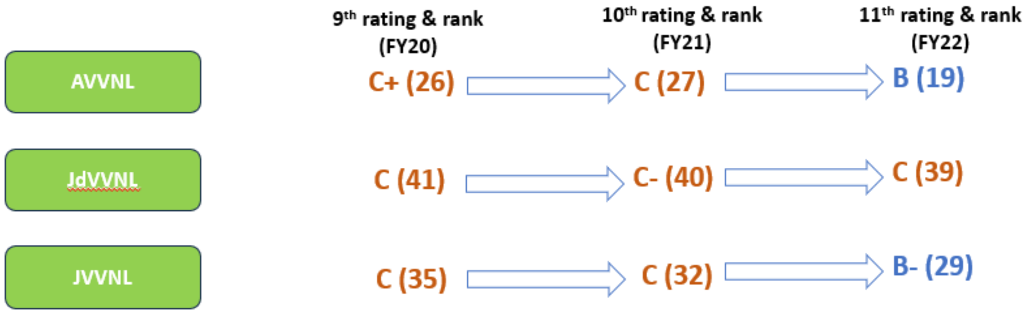
Since 2012, the PFC has been undertaking the Annual Integrated Rating Exercise under the approval and guidance of the MoP. Based on the audited and provisional annual accounts of discoms, this exercise assesses the discoms' performance to support sector stakeholders in action areas for future progress. In addition, the discoms' performance as per this rating determines the lending terms offered by PFC and REC Limited, a major debt source for Indian discoms. As of FY22, 53 per cent (~INR 35,000 crore) of the total loan requirements of Rajasthan discoms is met by REC and PFC.[63]

Over the past three rounds, all three state discoms have improved their rating or rank (Figure 5.5). In fact, Rajasthan discoms are amongst the top 10 discoms across India, with the highest improvement in AT&C losses. AVVNL was ranked 19th among all discoms, while JdVVNL and JVVNL were ranked 29th and 39th, respectively (Figure 5.5). A shift in the ratings of Rajasthan discoms to the A+ category could help reduce their interest burden for loans secured from REC and PFC by 0.75 per cent to 1.00 per cent (Table 5.2). In terms of avoided interest costs, this could translate into savings worth ~INR 320 crore per annum or ~INR 2,380 crore over five years (when compounded quarterly).[64]

[63] Analysis based on data from discoms' balance sheet.

[64] To calculate reduction in interest cost annually and over five years with shift in grade, we computed the total interest (compounded quarterly) of each discom (both for one and five years) corresponding to rate linked to their current grade and, similarly, calculated interest corresponding to the rate (9.75 per cent) linked to A+ grade. The difference between the (aggregate) interest amount for the two rate of interest are the savings for the discoms.

Figure 5.5: Some improvement of grades and ranking observed across Rajasthan discoms



Source: Authors' illustration based on PFC (2023a)

Table 5.2: With lower grades, the interest rates of PFC and REC loans increase

	Grades of discom as per the annual integrated ratings of discoms			
	A+	A	B	C
Rate of interest from March 2023 (%)	9.75	10.25	10.5	10.75

Source: Authors' compilation from REC and PFC documents

Identifying parameters that can help improve discoms' credit rating

Table 5.3 shows parameters considered in PFC's 11th Annual Integrated Rating for grading discoms and the scores of Rajasthan discoms across these parameters. Of the total base score of 100, AVVNL scores the highest amongst all three discoms, and JdVVNL scores the lowest. There are opportunities to improve scores across several parameters through short-term and medium-term actions. Discoms, with support from the state government and RERC, can improve their grade through following short- and medium-term interventions.

Short term actions

- **Timely filing of the tariff petitions** by discoms **and release of tariff orders** by RERC can improve scores by 2-3 marks.[65]
- **Ensuring 100 per cent collection efficiency** for three consecutive years can help discoms gain 1.3-2.7 marks. In FY22, Rajasthan discoms already reported 100 per cent collection efficiency. Discoms must continue realising 100 per cent collection efficiency in the coming financial years.

[65] Timely issue and implementation of the annual tariff order by 1 April of the current FY is one of the pre-qualification criteria under Revamped Distribution Sector Scheme (RDSS) (REC 2023).

Table 5.3: Rajasthan discoms' scores against different parameters determining discoms' ratings

Themes	Parameters		AVVNL	JVVNL	JdVVNL
		Max. score	B	B-	C
Financial sustainability (75 marks)	ACS – ARR Gap (cash adjusted)	35	35	28.8	10.5
	Days Receivable	3	3	3	3
	Days Payable to GenCos & TransCos	10	0	0	0
	Adjusted Quick Ratio	10	2.8	0.9	1.6
	Debt Service Coverage Ratio (cash adjusted)	10	4.4	3.4	0
	Leverage (Debt/EBITDA) (cash adjusted)	7	6.2	0	4.7
Performance excellence (13 marks)	Distribution Loss (SERC approved)	2	2	0.8	0
	Billing Efficiency (%)	5	1.8	0.2	0
	Collection Efficiency (%)	5	3.7	3.5	2.3
	Corporate Governance	1	0	0	0
External Environment (12 marks)	Subsidy Realized (Last 3 FYs)	4	1.6	1.9	0.6
	Loss Takeover by State Govt.	3	3	3	2.8
	Government Dues (Last 3 FYs)	3	2.9	2.6	2.7
	Tariff Cycle Timelines	1	0	0	0
	Auto Pass Through of Fuel Costs	1	1	1	1
	Gross score	**100**	67.4	49.1	29.1
Special disincentives (-66.5 marks)	Auditor's Adverse Opinion	-15	0	0	0
	Availability of audited accounts	-15	0	0	0
	Default to banks/Fis	-15	0	0	0
	Audit Qualifications	-4	-1	-1	-2
	Governance (Audit committee)	-3	0	-1	0
	Tariff cycle delays	-4.5	-1.3	-1.3	-1.3
	Tariff independent of subsidy	-1	0	0	0
	Uncovered revenue gap (current year)	-4	0	0	0
	Regulatory assets	-5	-3.1	-3	-5
	Total disincentives	**-66.5**	-5.3	-6.3	-8.3
	Net score		**62.1**	**42.8**	**20.9**

Source: Authors' analysis based on PFC (2023a)

Note: Rows in grey and orange indicate parameters where short-term and medium-term actions can help two or more discoms improve their score by one or more.

- **The realisation of government subsidies and dues** will help discoms gain 2.5-3.7 marks. The tariff subsidy received against booked increased from 57 per cent in FY20 to 77 per cent in FY21 to 117 per cent in FY22 (PFC 2021; 2022; 2023b). This shows that the government has also cleared some previous years' arrears in tariff subsidies in FY22. Going forward, the state government must clear the pending subsidy receivables of ~INR 15,500 crore (MoP 2023a).
- **Adopting corporate governance norms,** i.e., the presence of a Board with one-third independent directors, can also help all discoms gain one mark each.

Medium-term actions

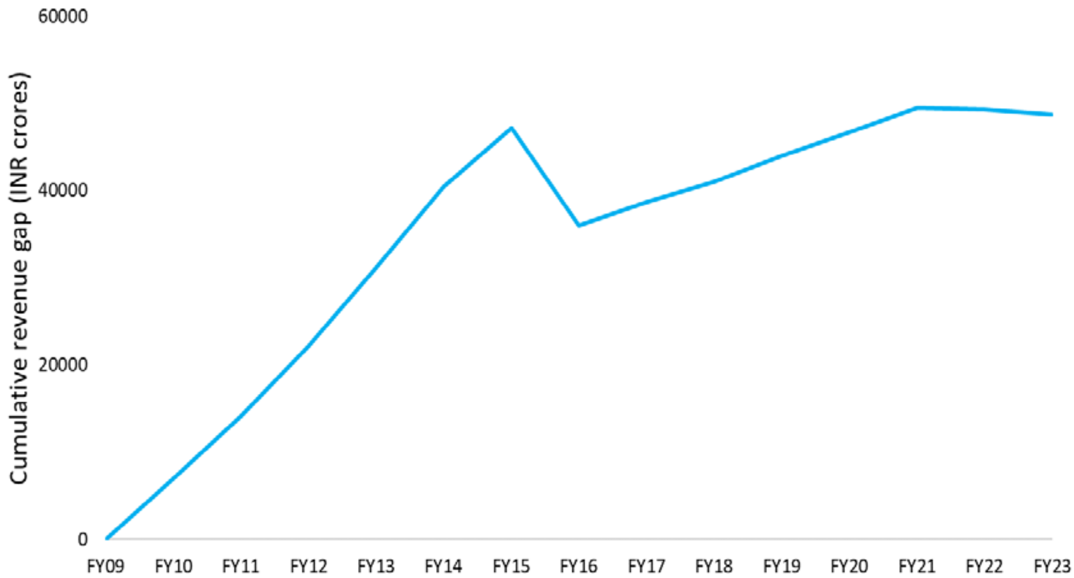
Interventions to improve financial sustainability parameters can help Rajasthan discoms improve their base score by 23-55. Similarly, discoms can gain 5-10 marks by improving their billing and collection efficiency performance. Below, we discuss three key areas.

- **Reducing days payable to generating companies:** In FY22, Rajasthan discoms had a high average of 144 days for payments made to generating companies against power purchases (PFC 2023b). Even bringing this down by half will help discoms improve their score by six marks. Thus, discoms must focus on improving payment discipline, which has already begun owing to implementation of the LPS Rules.
- **Reducing ACS-ARR gap:** Average Cost of Supply (ACS)-Average Revenue Realised (ARR), or the per unit revenue gap, is a major parameter in grade determination and primarily contributes to changes in ranking and grade. From FY20 to FY22, Rajasthan discoms have shown significant improvement across this parameter. While the ACS-ARR (cost-adjusted) difference was INR 13,652 crore in FY20, the discoms reported a surplus (barring JdVVNL) of INR 2,198 crore in FY22. The improvement is mainly due to high subsidy disbursal by the state government. Sustaining a negative or zero revenue gap going forward will require concerted efforts to improve billing and collection efficiency, improve demand forecasting accuracy, undertake demand-side management efforts (including implementation of KUSUM and Time-of-Day tariff) and optimise power procurement costs (as discussed in Chapter 4).
- **Reduction in distribution loss and improved billing efficiency** would help the discoms increase their scores by 3.2-7 marks. Leveraging smart meters under the Revamped Distribution Sector Scheme can be one of the key enablers for this change (see section 5.5).
- **Bringing down the regulatory assets:** To improve their financial standing and further improve their rating (by 3.1-5 marks), discoms in Rajasthan must devise a plan to dissipate their huge accumulation of regulatory assets (unfunded revenue gap) that puts a significant burden on consumers through high-interest costs (discussed next).

5.4 Dissipating the unfunded revenue gap of discoms

Over the last decade, the practice of allowing a share of distribution companies' (discoms') cost/expenditure for recovery in future years (termed as 'unfunded revenue gap' or 'regulatory assets') has made discoms and consumers in Rajasthan caught up in a vicious financial stress cycle. The cumulative unfunded revenue gap currently stands at INR 48,723 crore (until FY23) (RERC 2023a),[66] and it has increased at a CAGR of 11 per cent since FY11 (Figure 5.6).

Figure 5.6: Cumulative revenue gap increased at a CAGR of ~11 per cent between FY11 and FY23



Source: Authors' analysis from RERC's true-up orders of FY09-FY22 and tariff orders for FY23 & FY24.

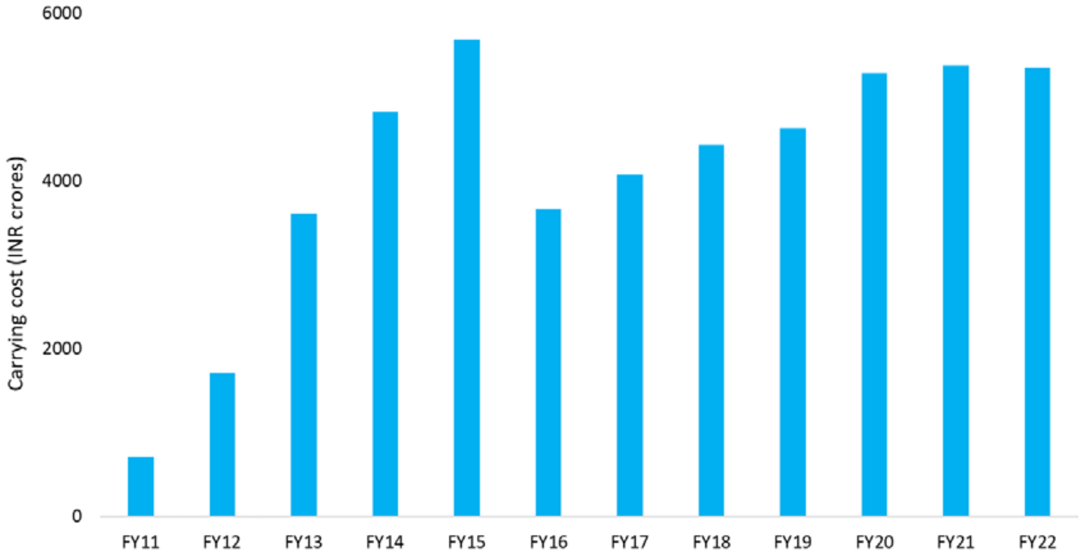
Note: GoR took over the entire revenue gap until 2009. The current revenue gap has accumulated since FY10; however, a dip is visible in FY16 due to the Ujjwal Discoms Assurance Yojana (UDAY).

Accumulation of the revenue gap currently results in carrying costs (or interest cost) burden on consumers equivalent to 8-10 per cent (INR 0.58/kWh) of the average electricity tariff.[67] Cumulative carrying costs of ~INR 49,300 crore have been allowed on the accumulated unfunded revenue gap between FY2011 and FY2023 (Figure 5.7). Based on the latest tariff order for FY 2024, the annual carrying costs (~INR 5300 crore) comprised 72 per cent of the total interest and finance charges of the discoms (~INR 7,327 crore).

[66] Based on Tariff Order for FY24. This is despite the deduction of INR 15,980 crore from the cumulative unfunded revenue gap under the UDAY scheme in FY16.

[67] Unlike RERC, we have not included interest cost on UDAY loans as part of the carrying cost to arrive at per unit carrying cost.

Figure 5.7: A carrying cost of ~INR 49,300 crore was allowed between FY11 and FY23



Source: Authors' analysis from RERC's true-up orders from FY11 to FY22 and tariff order for FY23.
Note: Carrying cost for FY13 is not shown because of the non-availability of a true-up order.

Recovery of the accumulated unfunded revenue gap of INR 48,723 crore in a single year would require a tariff hike of 72 per cent, a tariff shock to the consumers. However, if the status quo remains, we estimate that the consumers would be levied with a carrying cost of INR ~52,000 crores over the next decade, with the unfunded revenue gap remaining unrecovered. Therefore, working out a dissipation schedule is crucial to break the vicious cycle.

In the medium to long run, a dissipation schedule will reduce the interest cost and revenue gap burden on consumers, leading to lower electricity bills, and simultaneously improve cash flows and the financial position of the discoms.

A two-pronged approach for staggered and time-bound recovery of the gap

Lever 1: Swapping of discoms' expensive loans against unfunded revenue gap with cheaper debt

In Rajasthan, discoms are allowed an average carrying cost of 10.87 per cent on the accumulated revenue gap. On the other hand, the coupon rates on the recently issued state government-guaranteed bonds have been 100-200 basis points (bps) lower on average (8.95-9.95 per cent) (Tip Sons, n.d.). It is proposed that the discoms should try to swap their existing costlier loans against the accumulated revenue gap with cheaper debt. This measure could save INR 480-960 crore in carrying costs annually**.** The options might include:

1. **Transitional financing mechanism**, linked with renewable energy procurement, energy transition parameters, performance and efficiency improvement targets for the discoms. Previously, government-backed transitional loans have been used under the UDAY scheme and during COVID-19 to improve discoms' financial position.

2. **Government-guaranteed bonds** on a private placement basis to pre-selected institutional investors, i.e. the banks, mutual funds, LIC, etc. The Tamil Nadu Generation and Distribution Corporation (TANGEDCO) is using such a facility to raise ~INR 7,605 crore at a lower coupon rate to repay its high-cost loans and reduce its interest cost burden (Government of Tamil Nadu 2023).

These loans (or bonds) would form part of the contingent liabilities of the GoR and, therefore, would not increase its strained outstanding liabilities under the Fiscal Responsibility and Budget Management (FRBM) Act.[68]

Lever 2: An additional surcharge for time-bound recovery of accumulated unfunded revenue gap

For FY24, GoR's fiscal deficit target is 3.98 per cent of the gross state domestic product (GoR 2023b), which is higher than the permissible limit of 3 per cent under the Rajasthan FRBM Act (GoR 2005) plus the additional 0.5 per cent limit allowed to carry out power sector reforms (Ministry of Finance 2022). Considering the state government's tight fiscal position, the possibility of additional funds to dissipate the legacy unfunded revenue gap appears challenging. Further, using the annual regulatory surplus (if any) to dissipate the gap, as observed by the RERC in the tariff order for FY24, can potentially prolong its recovery to an indefinite period.

A regulatory surcharge can facilitate the discoms to generate additional revenue over its annual costs to liquidate the accumulated gap in a time-bound manner. It can be levied on an INR/unit (i.e., a surcharge on total electricity units consumed) or percentage basis (i.e., a surcharge on consumer bill (fixed plus energy charge)). However, as demonstrated in Annexure VIII, the per-unit surcharge is inequitable and burdens low-income consumers more. Tables 5.4 and 5.5 below illustrate the impact of imposing a percentage-based regulatory surcharge on consumers' bills under two options.

[68] Based on CEEW analysis of FY22 data, GoR has an additional space of INR 52,577 crore for providing guarantees under the FRBM limit.

Option 1 is an exclusive levy of regulatory surcharge. Option 2 is combining regulatory surcharge with swapping for cheaper loans. Depending upon which option is chosen:

- **The additional impact on consumers' tariff would be INR 0.35/kWh (average for three discoms), and the unfunded revenue gap would recover in 5-6 years for AVVNL, 7 years for JVVNL, and 8-9 years for JdVVNL.**
- **With the dissipation schedule, consumers would save on paying a carrying cost of ~INR 14,000 to 17,000 crore in the near-term.**

Table 5.4: The imposition of an additional surcharge of ~5 per cent on consumer bills can dissipate the accumulated unfunded revenue gap in 6 to 9 years and save carrying costs of ~INR 13,800 crore

Particulars	**ID**	**JdVVNL**	**JVVNL**	**AVVNL**	**Total**
Opening revenue gap (RG) for FY25 (INR crore)	A	18,502	17,844	11,486	47,832
Carrying cost on RG @ average long-term loan interest rate	B	11.10%	10.75%	10.69%	10.87%
Percentage-based regulatory surcharge *(proposed to be levied on consumer bills (fixed plus energy charge))*[69]	C	12.80%	12.80%	12.80%	12.80%
Annual carrying cost averted over the dissipation period[70] (INR crore)	D	6,269	4,630	2,942	13,842
Number of years until (C.) dissipates (A.)	E	9	7	6	6-9
Impact of regulatory surcharge on consumer tariff in FY25 (INR/unit)	F	0.21	0.37	0.48	0.35

Source: Authors' analysis

Notes:

1. The percentage-based regulatory surcharge of 12.8 per cent (recovery of INR 8,481 crore in FY25) in Table 5.4 includes recovery of carrying cost (~INR 5,200 in FY25). The carrying cost is built in the current tariff and is billed to the consumers. Therefore, the additional burden, net of carrying cost, on the consumers comes at INR 3,281 crore (i.e., ~5 per cent of projected revenue recovery from consumers of ~INR 66,254 crore in FY25).
2. Carrying cost of 11.10 per cent, 10.75 per cent, and 10.69 per cent for JdVVNL, JVVNL, and AVVNL is based on the tariff order for FY24.
3. Revenue gap/surplus from FY25 onwards has been assumed as zero.
4. Assumed annual revenue growth rate @ 8 per cent as per past trends from RERC tariff and true-up orders.
5. Assumed annual sales growth rate @ 3 per cent as per past trends from RERC tariff and true-up orders.
6. The number of years for dissipation might increase with an increasing share of commercial and industrial consumers migrating towards other modes of power procurement under the Green Open Access Rules and captive transactions.

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[69] RERC, in its tariff orders, approves a uniform tariff structure across discoms. Therefore, we have proposed uniform regulatory surcharge rates.

[70] Averted carrying cost has been calculated as the difference between annual carrying cost under option-1 versus under the counterfactual of no dissipation, added over the number of years until dissipation (E.) for each discom.

Table 5.5: Swapping of discoms' expensive loans against unfunded revenue gap with cheaper debt, together with a surcharge of ~5 per cent, can dissipate the accumulated unfunded revenue gap in 5 to 8 years and save carrying costs of INR ~17,300 crore

Particulars	ID	JdVVNL	JVVNL	AVVNL	Total
Opening revenue gap (RG) for FY25 (INR crore)	A	18,502	17,844	11,486	47,832
Current carrying cost on RG @ average LTL interest rate	B	11.10%	10.75%	10.69%	10.87%
Reduction in carrying cost after loan swapping (in %)	C	2.00%	2.00%	2.00%	2.00%
Carrying cost on RG @ average LTL interest rate	D=B-C	9.10%	8.75%	8.69%	8.87%
Ad valorem regulatory surcharge	E	12.80%	12.80%	12.80%	12.80%
Annual carrying cost averted over the dissipation period (INR crore)	F	7,562	6,913	2,809	17,284
Number of years until (D.) dissipates (A.)	G	8	7	5	8
Impact of regulatory surcharge on ABR in FY25 (INR/unit)	H	0.21	0.37	0.48	0.35

Source: Authors' analysis

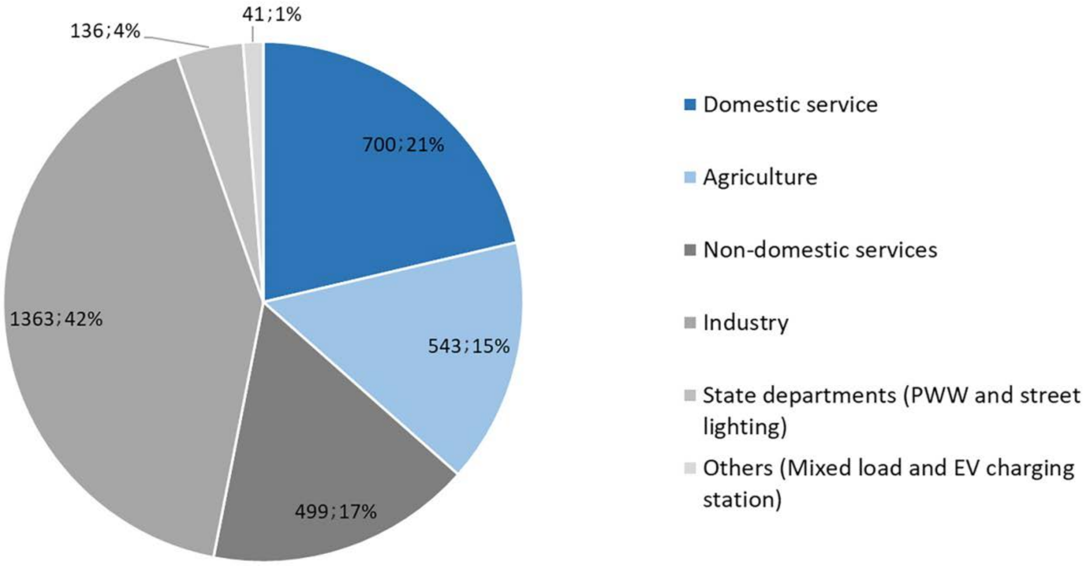
Notes:

1. The percentage-based regulatory surcharge of 12.8 per cent (recovery of INR 8,481 crore in FY25) in Table 5.5 includes recovery of carrying cost at 8.87 per cent (~INR 4,243 crore in FY25). This lower carrying cost is built in the current tariff and is billed to the consumers at a higher rate of 10.87 per cent (~INR 5200 crore). Therefore, the additional burden, net of carrying cost, on the consumers comes at INR 3,310 crore in FY25 (i.e., 5 per cent of projected revenue recovery from consumers of ~INR 66,254 crore in FY25)
2. Carrying cost of 11.10 per cent, 10.75 per cent, and 10.69 per cent for JdVVNL, JVVNL, and AVVNL is based on the tariff order for FY24.
3. Revenue gap/surplus from FY25 onwards has been assumed as zero.
4. Assumed annual revenue growth rate @ 8 per cent as per past trends from RERC tariff and true-up orders.
5. Assumed annual sales growth rate @ 3 per cent as per past trends from RERC tariff and true-up orders.
6. The number of years for dissipation might increase with an increasing share of commercial and industrial consumers migrating towards other modes of power procurement under the Green Open Access Rules and captive transactions.

The proposed solution will have a limited impact on low-consumption domestic and agricultural consumers. Figure 5.8 below depicts the projected consumer category-wise additional burden of imposing a percentage-based regulatory surcharge of 12.8 per cent (from option 2) at regulator-determined tariff rates, i.e., without including the government's subsidy obligations. From the figure, domestic and agricultural consumers are expected to experience a burden INR 700 crore and INR

543 crore, respectively, in FY25. However, after including GoR's subsidy support of 2,000 free units to every agricultural consumer and 100 free units to every domestic consumer, the effective burden reduces to a maximum of ~INR 207 crore and ~INR 276 crore, respectively. Therefore, the proposed dissipation schedule is expected to have a limited impact on the low-consumption and price-sensitive domestic and agricultural consumers.

Figure 5.8: Consumer category-wise additional burden of ~INR 3,281 crore in FY25 without government subsidy obligations



Source: Authors' analysis based on the proposed dissipation schedule in Table 5.5.
Note: 1. Values in (INR crore, share in total)

Revisiting the accounting mechanism for recovered unfunded revenue gap

In RERC's tariff and true-up order(s), the current accounting mechanism does not clarify whether carrying cost is getting recovered from consumers or added to the revenue gap. This distinction is important to identify which expenditure components contribute to the revenue gap increase. A time-bound recovery of the revenue gap requires clear and separate accounting of the revenue gap and its associated carrying costs.

It is recommended that a separate table for accounting for the unfunded revenue gap, carrying cost allowed and the gap recovered through regulatory surcharge shall be incorporated. The regulatory surcharge should be levied separately in the electricity bills for consumers. For discoms, regulatory surcharges should be reported separately in their billing database. The Uttar Pradesh Electricity Regulatory Commission has followed a similar approach.[71]

[71] See UPERC (2017): Approval of Business Plan, MYT ARR and Tariff for State Discoms for FY18 to FY20 and True-up of FY15.

Key recommendations for dissipating discoms' unfunded revenue gap

1. **Swap expensive loans against unfunded revenue gap with cheaper debt and levy regulatory surcharge:** Swapping expensive loans with cheaper debt through government-backed transitional finance or bonds issued on a private placement basis can potentially reduce the carrying costs for consumers by 200 bps. Alongside this, a regulatory surcharge can facilitate the discoms to generate additional revenue over its annual costs to liquidate the accumulated unfunded revenue gap in a time-bound manner. Imposing a regulatory surcharge of five per cent can dissipate the accumulated unfunded revenue gap in six years for JVVNL, seven years for JdVVNL, nine years for AVVNL. It can potentially save up to INR 18,000 crore in carrying costs at a modest additional cost of INR 0.25 to 0.35/unit for the consumers.

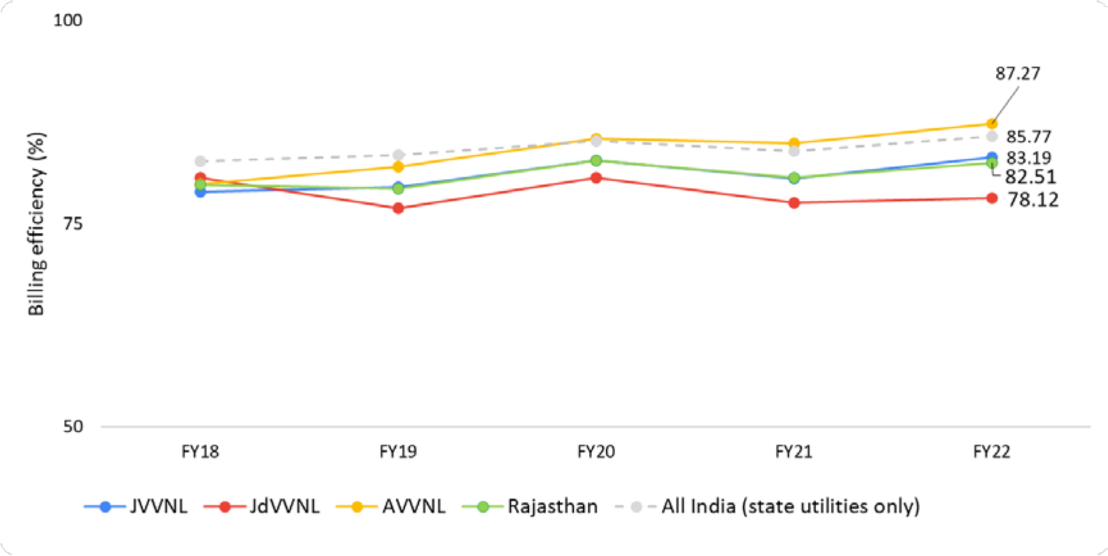
2. **Revisit accounting mechanism for revenue gap and carrying cost recovery:** Regulatory surcharge should be levied separately on consumer electricity bills. For discoms, they should be reported separately in their billing database. Clear and separate accounting of the revenue gap and associated carrying costs will improve transparency and allow their time-bound recovery.

5.5 Leveraging smart meters to improve operational efficiency of Rajasthan Discoms

As discussed earlier, Rajasthan discoms have improved their AT&C losses over the past three years, mainly on account of improved collection efficiency. However, billing efficiency has not contributed much and remained in the range of 78-87 per cent in FY22. Overall, the state discoms' billing efficiency is less than the national average by more than three per cent (Figure 5.9).

Poor billing efficiency is the result of electricity theft, provisional and underbilling of consumers, poor distribution infrastructure and unmetered agriculture sales. **The Government of India launched the RDSS in 2020 to address such inefficiencies. The Scheme aims to support discoms in enhancing their financial performance, with smart prepaid meter deployment as a key pillar of change.**

Figure 5.9: Rajasthan discoms' billing efficiency reduced by 0.26 per cent in FY22 compared to FY20



Source: Authors' analysis based on PFC reports

Under the RDSS, Rajasthan discoms have planned to install 1.4 crore smart prepaid meters in two phases by FY25 (Table 5.6). Around six lakh smart meters have been installed, and 80 per cent are installed in the distribution region of JVVNL. Rajasthan has almost completed 100 per cent feeder metering, and DT metering is expected to be completed by December 2023 (MoP, n.d.). Discoms would need to invest ~INR 8,500 crore in its smart metering infrastructure.

Table 5.6: Rajasthan discoms plan to cover 1.4 crore consumers with smart prepaid meters by FY25

Discom	Consumer smart meters	DT meters	Consumer meters covered across phases		Cost of smart metering (INR Cr.)
			Phase 1	Phase 2	
AVVNL	5,432,231	155,453	22%	78%	3,259
JVVNL	4,762,643	111,346	46%	54%	2,858
JdVVNL	4,080,082	167,809	33%	67%	2,448
Rajasthan	14,274,956	434,608	34%	66%	8,565

Source: Authors' compilation based on RDSS Action Plan obtained from Rajasthan discoms

Rajasthan discoms must focus on three key fronts to make good on these investments:[72]

1. Effective consumer engagement and awareness strategy
2. Designing and developing system architecture for secure and integrated data storage, sharing and management system

[72] These themes have been developed based on learnings gathered through the survey of smart meter consumers and engagements with officials from discoms in MP, Assam and Bihar on their experiences and best practices.

3. Strengthening institutional capacity to leverage smart meter data for efficiency in billing and operations

Lever 1: Effective consumer engagement and awareness strategy

Consumer engagement and awareness are critical to removing roadblocks to effectively operating the smart metering infrastructure. During February-March 2022, CEEW conducted a consumer perception survey with 2,700 smart-metered consumers across six leading states, including Rajasthan (Agrawal et al. 2023). Below, we summarise key insights on the perception of smart meter users in Rajasthan.

- **A vast majority of smart meter users (95 per cent) found the installation process smooth.**
    - Only 34 per cent received detailed information about smart meters during installation.
- **Only 41 per cent of smart meter users were satisfied with their billing and payment**, 5 per cent were dissatisfied, and the rest were neutral.
    - 70 per cent of users reported better billing regularity with smart meters, and some users reported that payments have become easier due to mobile apps. However, satisfaction levels are significantly lower than that reported in Assam (93 per cent) and Bihar (53 per cent). In fact, 23 per cent of users in Rajasthan said they would not recommend smart meters to their peers (highest among all six states), potentially due to a lack of perceived benefits.
- **Perceived co-benefits of smart meters a key driver of satisfaction**
    - Across six states, ~40 per cent of users reported feeling a greater sense of control over electricity expenses, improved supply quality in their locality, and a drop in instances of electricity theft. However, less than 10 per cent of users in Rajasthan reported any perceived benefits of the technology.
- **Consumers also reported certain challenges that need to be redressed:**
    - **Limited awareness and use of mobile apps.** About 40 per cent of smart meter users in Rajasthan were aware of the mobile apps, and 35 per cent were using them. In Bihar, 80 per cent of surveyed households reported using smart meter mobile apps.
    - **Lack of access to detailed bill breakup.** Half of the smart meter users in Rajasthan reported their inability to access detailed bills due to poor digital literacy and limited use of smart meter apps.
    - **Perceived increase in electricity bills**. Many consumers using smart prepaid meters (in other states) reported a perceived rise in electricity bills after smart meter installations. This was linked to users' limited

awareness of how bills are deducted (especially deductions of arrears, fixed and additional charges).

- **Delays in recharging and reconnection.** For a third of disconnected prepaid smart meter users, it took more than 30 minutes to reconnect after a successful recharge.

In summary, the above findings indicate that the past (non-RDSS) smart meter deployments in Rajasthan have only partly influenced consumer satisfaction, with very few users realising the multiple benefits of this technology. Users' experience in other states indicates that a greater role of discoms in supporting the uptake of smart meter mobile apps, ensuring access to and awareness of bill composition, and smooth recharge/reconnection experience will be critical for the next phase of deployments under RDSS.

Key action points to improve consumer satisfaction with smart meters

To ensure that the consumers can fully utilise the functionalities of smart prepaid meters and discoms can make good use of the investments in smart metering infrastructure, we propose the following recommendations for Rajasthan discoms.

a. Design a comprehensive consumer engagement plan to build consumer confidence and address their concerns.

b. Use multiple channels to regularly communicate with consumers about smart meters and mobile applications, especially for prepaid meters. In addition, organising camps before installation rollout to address consumer concerns and dispel incorrect perceptions through live demonstrations

c. Prepare guidelines on Consumer Rights (Smart Meter Users) and take regulatory approvals for the same. Also, formulating a dedicated team at 1912 cell to promptly resolve (smart meter-specific) grievances would be beneficial.

d. Further, using check meters to address consumers' concerns in locations with high resistance against smart meters, especially concerning the perception of high bills after smart metering.

Lever 2: Designing and developing system architecture for secure and integrated data storage, sharing and management system

Smart prepaid metering of consumers and system metering (including feeder and DTs) will generate a substantial amount of high-frequency data. The enormous amount of data generated by these smart meters can help power distribution companies (discoms) to improve system efficiency, flexibility and reliability**.** Smart meters present multiple opportunities for discoms and consumers, but their fulfilment rests on the discoms’ appreciation of and capacity to realise these. Importantly, discoms can also use smart meter infrastructure to empower consumers with their consumption data and customized feedback to facilitate energy budgeting and provide reliable power supply.

However, this would entail designing and deploying a robust system architecture that ensures interoperability between the meter data management system (MDMS), discoms legacy systems and discoms billing platform for effective data use. In addition, the system should be able to address the concerns about securing high-frequency data from unauthorised access and cyber risk development (Aggarwal et al. 2023). For this, the discoms need to invest in developing the right ecosystem, which should include:

a. **Suitable provisions for system integration in AMISP contracts right from the RFP stage.** These can include the development of communication nodes in the system for cross-sharing of actionable insights across other departments, such as vigilance and revenue and data management provisions and efficiently with a framework to ensure consumer data privacy with limited access to data as per the hierarchy and functional roles.
b. **Provisions for periodic third-party audits** to ensure adequate safeguards are in place for data protection and secure the system against cyber threats.
c. **A dedicated in-house team** that understands the system architecture and is in constant touch with the AMISPs to resolve the issues faced during or post-deployment. The team also monitors the rollout and its impact and ensures AMISP's accountability to the Service Level Agreements (SLAs).

Lever 3: Strengthening institutional capacity to leverage smart meter data for efficiency in billing and operations

Effective use of smart meter data can help discoms reduce under-billing, especially in high-loss areas. So far, there has been limited utilisation of the smart meter data globally (Henriot 2023). For instance, most utilities in the US are leveraging smart meters to offer time-of-use (ToU) tariffs and energy-use feedback to their customers, but other opportunities remain under-exploited (Walton 2020). Indian state discoms can also leverage the data generated to develop use cases for business analytics such as consumer load and consumption profiling, identifying nodes or locations with high losses, developing pricing strategies for consumers to incentivise demand management, etc.

There has been limited use of the rich smart meter data for decision-making in Rajasthan discoms, and the lack of adequate manpower and skills is a key constraint. Even though services can be outsourced to third parties, a dedicated team of discom for smart metering and IT operations is critical for programme success. We propose:

- **Creating dedicated smart meter units in each discom**, which is well staffed and supported by analysts to analyse the smart meter data and prepare use cases for deriving actionable insights from the smart meter data.

- **Conducting periodic training for discom staff in headquarters and field till subdivision level to empower them to leverage the benefit of smart meters and derive** insights from available data and dashboards.
- **Build a new cadre of discom staff qualified in IT systems** and adept at advanced data analytics in the medium term. This would ensure improving management of IT assets and development of in-house applications and middleware and restrict unauthorised access.

The digitalisation of distribution networks and operations is a journey on which the Rajasthan discoms must innovate and test solutions and strategies that could be scaled up. The learnings from Bihar and Assam discoms (which are ahead in the rollout) can be utilised, which have taken up smart meter deployments into small packages, area-wise. This ensures that key insights and learnings from the earlier deployments are incorporated in the next rollout. Any course correction required regarding deployment, technology, communication strategy, etc., can be incorporated into future rollouts. At the same time, having multiple AMISPs owing to smaller packages helps create a market of several products and services such as MDMS, HES, communication technology, dashboards, analytics, etc.

Under RDSS, the near-term focus of the discoms will be on achieving the smart meter deployment targets within the ambitious three-year timeline. In parallel, Rajasthan discoms must also develop strategies and bolster institutional capacity to leverage this digital infrastructure to realise its potential, including to meet the scheme's primary objective.

6. 2030 ROADMAP FOR RAJASTHAN'S POWER SECTOR TRANSITION

This section outlines the Power Sector Transition Roadmap for Rajasthan as a series of steps to be implemented by or before 2030 to build the cost-effective RE-rich power system envisioned in this document. The Roadmap (Table 6.1) has been made after multiple rounds of stakeholder consultations and is based on the current understanding of technologies and institutional capacities. The proposed timelines may vary based on the pace of technological developments and the implementation momentum.

6.1 Principles for drafting the Roadmap

While each of these institutions must take the lead in implementing certain steps, all of them must work in tandem to create a facilitative ecosystem for the transition. For example, a robust IRP exercise would require spatially and temporally granular historical load data from the discoms and on operational characteristics of generating units from RRVUN and the SLDC. Efficient scheduling would require timely billing by RRVUN and notification of the MoD stack by RUVNL using the methodology notified by the RERC. The proposed Roadmap reflects the need for coordination between various institutions by grouping the implementation steps by objective.

Further, some of the proposed steps are more foundational and urgent and can be implemented in the short term; others require closer deliberation and further analysis. For example, setting an ambitious policy target of installing 80-90 GW of VRE within Rajasthan by 2030 would signal the state government's intent to market players and stakeholders. However, designing a workable framework for the state and Union governments to share the costs of flexibilisation of thermal plants may take longer. Thus, phasing various implementation steps across the short- and medium-term represents their urgency and feasibility.

Table 6.1: Proposed Energy Transition Roadmap for Rajasthan's power sector

Objective	Lead institution	Short-term (1-2 years)	Medium-term (3-4 years)
Raising policy ambitions	Government of Rajasthan (GoR)	Define enhanced RE targets of 80-90 GW by 2030 (aligned with national clean energy targets) Update the State Solar Energy and Wind and Hybrid Energy Policies	Periodically monitor the state's progress in achieving these targets and mitigate emerging challenges, if any
	RERC	Ensure enforcement of the RPO regulations and imposition of the penalties in case of shortfall in meeting RPO targets.	Establish an appropriate rewards framework for obligated entities that comply with and surpass their RPO targets.
Roadmap for cost-effective integration of RE in Rajasthan's power grid			
Integrated Resource Planning (IRP)	Energy Department, GoR	● Develop an institutional coordination mechanism for conducting IRP exercise every 3 years ● Allocate funds for procuring tools, data architecture and flows, staffing, and collaborations	
	RERC	Mandate IRP submission as part of the ARR process and establish an IRP evaluation desk at RERC and align procurement planning process with the CEA resource adequacy guidelines	Ensure that inputs considered, models utilised, and outputs of the model as part of the IRP are publicly available and stakeholders and civil society organisations (CSOs) are enabled to participate in the public consultations on the IRP and tariff setting processes.
	RUVNL	Institutionalise the IRP process in discoms and prepare a detailed integrated resource plan for the state	
	Discoms	Establish systems and resources to conduct granular demand forecasting every year for a 5-year horizon. Prepare procurement plans based on these demand forecasts	

Objective	Lead institution	Short-term (1-2 years)	Medium-term (3-4 years)
Enabling efficient use of resources through wholesale markets	Energy Department, GoR	Facilitate implementation of national mechanisms to trade surplus power under existing contracts (when available) between discoms	Address inflexibilities in current PPAs in coordination with CERC and MoP
	Discoms	Use advance forecasting tools for accurate demand as well as RE generation forecasting for bringing efficiencies in scheduling of resources	
	RERC	• Ensure quantification of costs and benefits to the state because of expanding SCED to intra-state generators • Create norms for post facto approval of short-term power purchase by the discoms as part of the true up process.	• Conduct robust assessments to ascertain the impact of MBED on state discoms' procurement and finances. • Implement regulatory sandboxes for participation of the state assets in pilots seeking to optimise despatch.
Enabling deployment of storage solutions to enhance flexibility, manage demand, and provide ancillary services	RRECL	Identify prospective sites for large as well as off-river pumped storage hydro (PSH) projects and conduct due diligence on land, hydrological, and environmental considerations for their development	
	SLDC	Conduct system simulations to ascertain requirement of balancing resources including ancillary services	Test the use of storage to manage real-time deviations in demand and supply
	Energy Department, GoR	Allocate a budget to provide capex-linked support for the energy storage pilots Develop a roadmap to achieve the state's energy storage obligation (ESO) targets of 2030 in coordination with discoms, RUVNL, RVPN, SLDC and RERC	Allocate a budget to support energy storage pilots based on advanced chemistries that are likely to perform efficiently in state's ambient conditions.
	Discoms and RVPN	Initiate pilot projects based on a diverse set of BESS technologies for various applications	

Objective	Lead institution	Short-term (1-2 years)	Medium-term (3-4 years)
	RERC	● Enable and approve costs of pilots discoms and operators on various storage use cases. ● Provide inputs to CEA in devising technical and connectivity standards for storage applications at various levels.	● Assess the value of storage for considerations in pilots and resource adequacy studies. ● Ensure transparency and CSO/academia participation in testing phase and review of results and consultations on implementation plans. ● Devise regulations for storage procurement through new business models.
Facilitating the use of select hydro power plants to meet balancing needs	SLDC	In coordination with NLDC, lead pilots for scheduling the selected hydroelectric projects to serve peaking, ramping and ancillary requirements in the system.	MoP and state identify a framework to share the flexible hydro resource between hydro-rich and deficit states depending on the flexibility requirements.
Enhancing the flexibility of state's coal fleet	RRVUN	Conduct feasibility and cost-benefit analysis for retrofitting state-owned coal plants and identify candidate units for pilots	Devise and initiate implementation of a detailed plan for unit-wise investment for flexibilisation of state thermal plants
	RERC	● Introduce flexibility mandates for state-owned thermal fleet; enforce current operational flexibility norms set by CEA ● Notify guidelines for assessing and enhancing the ramping capability of state thermal units	Monitor the performance of the thermal power plants and devise penalties, like reduction of fixed costs to be approved, in case flexibility standards are not met or additional incentives in case of improvements in performance.
	Energy Department, GoR	Allocate funds to undertake retrofitting measures in select units as pilots	Develop and advocate a framework that can enable the centre and states to share costs for retrofitting

Objective	Lead institution	Short-term (1-2 years)	Medium-term (3-4 years)
Cost-effective operation of the state's thermal fleet	RERC	● Notify Merit Order Dispatch regulations or amend State grid code or Tariff Regulations ● Revise normative O&M expenses allowed for state-owned generation units in line with actuals or CERC norms	
	RUVNL	Prepare Merit Order Dispatch in line with notified principles/regulations by RERC	
	RRVUN	Share variable charges of plants with RUVNL within 10-15 days (or as defined in the MOD principles/regulations)	Enhance O&M practices to improve availability of thermal power plants
	Discoms	Create institutional and technical capacity to store and process granular load data required for advanced forecasting tools for higher accuracy load forecasting	● Reduce payable days to generating companies and adhere to prescribed norms under Late Payment Surcharge Rules, 2022 ● Leverage tariff and non-tariff mechanisms for demand side management
	Energy Department, GoR	Resolve issues of coal grade slippage in consultation with Coal India Limited, Indian Railways, Union Ministries of Power and Coal	
Upgrade grid technologies for better system control and enhanced communication abilities	RVPN and SLDC	Establish modern hardware and software systems for complete visibility of real-time RE generation	Ensure implementation of grid-asset monitoring systems such as sensors and advanced analytics that generate high-resolution data on grid conditions, system-integrity protection schemes, and digitalisation of substations
	RERC	Update state grid code to introduce provisions around providing reactive power support, and voltage and harmonics management	

Objective	Lead institution	Short-term (1-2 years)	Medium-term (3-4 years)
Roadmap for discoms to become enablers of energy transition			
Improving credit ratings of discoms	Discoms	• Timely filing of tariff petitions • Adopt corporate governance norms	
	RERC	• Timely release of tariff orders and moratorium on creation of regulatory assets (unfunded revenue gap) • Design performance based incentives or penalties for the metrics that affect the credit rating of the discoms like the T&D losses to be added or deducted in the annual revenue requirement	Ensure timely dissipation of unfunded revenue gap of discoms
	Energy department, GoR	• Clear tariff subsidy dues to the discoms and provide upfront subsidies in the future • Direct government departments to clear electricity dues in a timely/regular manner	
Dissipating the unfunded revenue gap of discoms	Discoms	• Explore transitional finance or private placement option for refinancing of unfunded revenue gap with cheaper loans • Co-develop a suitable dissipation plan with RERC and Energy department	
	RERC	• Levy regulatory surcharge for recovery of unfunded revenue gap • Revisit accounting mechanism for revenue gap and carrying cost recovery in the tariff order	
Leveraging smart meters to improve operational efficiency of Discoms	Discoms	• Prepare and implement a consumer engagement plan to build confidence in smart prepaid meters and improve uptake of mobile application	• Conduct periodic training of discom staff to equip them with tools to leverage smart meter infrastructure for efficient

Objective	Lead institution	Short-term (1-2 years)	Medium-term (3-4 years)
		• Create a dedicated team at 1912 call centre to resolve complaints of smart meter consumers (especially during roll out) • Include suitable provisions for system integration in AMISP contracts, including development of communication modules for sharing of actionable insights within and outside the discom • Create a monitoring unit to coordinate with AMISPs, monitor smart meter rollout and enforce Service Level Agreements with AMISPs • Create a dedicated smart meter unit, which is well staffed and supported by analysts to use smart meter data and prepare use cases for deriving actionable insights	operations and data-informed decision making • Undertake periodic third-party audits and ensure adequate safeguards for protecting smart meter data and securing the system against cyber risks • Build a new cadre of discom staff qualified in IT systems and adept at advanced data analytics
	RERC	• Ensure a uniform consumer experience with smart-meter technology • Monitor progress made on smart meter deployment and offer platform for consumer grievance redressal	

Source: Authors' compilation

6.2 Institutional framework

We propose a two-tier institutional framework for implementing the Roadmap presented in this document. Table 6.2 draws from the institutional arrangements under existing policies in the state, such as the Rajasthan Solar Energy Policy, 2019 (GoR 2019a) and the Rajasthan Wind and Hybrid Energy Policy, 2019 (GoR 2019b).

The State Level Empowered Committee (SLEC), chaired by the Government of Rajasthan's Chief Secretary, would be responsible for monitoring and coordinating the implementation of the Roadmap across state-level institutions and the Government of India on critical issues such as fuel supply or a cost-sharing mechanism to fund thermal power plant flexibilisation. The proposed SLEC may also include representation from other departments that indirectly affect or are affected by the power sector, such as Industries, Water Resources, Urban Development, etc. so that it can take a holistic view of the sector and the knock-on effects of the energy transition.

The proposed State Level Implementation Committee (SLIC) will operationalise the Roadmap and primarily comprises the institutions directly mandated to plan and operate the power system. The SLIC must convene more frequently than the SLEC to ensure close stakeholder coordination. The SLIC is proposed to have representation from a wider set of stakeholders, such as industry associations, civil society organisations and academia. The SLIC will also house the secretariat for the SLEC and the SLIC.

Further, electricity sector-specific rules and regulations form the levers for achieving most of the objectives of the Roadmap. As the power sector's regulator in the state, the Rajasthan Electricity Regulatory Commission (RERC) will play a pivotal role in implementing the Roadmap's steps and meeting its objectives. The institutional framework must be geared towards achieving alignment between the Roadmap and the regulations enacted by the RERC. Therefore, in addition to the SLEC and SLIC, the State Advisory Committee, constituted by RERC under Section 87 of the Electricity Act, 2003, with the Commission's members and the Principal Secretary of the Energy Department, GoR as *ex officio* members (RERC 2018), is another critical institutional coordination mechanism in the framework.

Table 6.2: Proposed institutional framework for the Energy Transition Roadmap

Members	Roles and responsibilities
State Level Empowered Committee (SLEC)	
• Chief Secretary, Government of Rajasthan (GoR) (Chairperson) • Chairman, RERC • Additional Chief Secretary, Finance, GoR • Principal Secretary/Secretary, Energy, GoR • Chairman, RRECL • Chairman and Managing Director, RVPN • MD, RRECL (Member- Secretary) • Representation from other departments as deemed necessary	• Monitoring implementation of the Roadmap • Liaise with the State Energy Transition Committee • Remove difficulties in implementation • Represent matters of state-wide importance to the concerned departments of the Government of India • Monitor progress via the mid-term report submitted by the SLIC and take necessary actions to ensure implementation
State Level Implementation Committee (SLIC)	
• Principal Secretary/Secretary, Energy, GoR (Chairperson) • Chairman & Managing Director, RVPN • MD, RRECL • MD, JVVNL • MD, AVVNL • MD, JdVVNL • MD, RUVNL • Joint Secretary, Energy, GoR – Convener Invited members: • Representatives from industry associations, civil society organisations and academic institutions	• Convene once in every two months to take stock of progress on steps as recommended under the Roadmap • Report progress to the SLEC every quarter • Refer matters to the SLEC for final approval where required • Prepare a report on the mid-term review of the Roadmap for submission to the SLEC and invite public comments on it • Apprise the RERC on emerging policy issues through representations in the State Advisory Committee meetings
Secretariat to the SLEC and SLIC	
Housed within the Energy Department, GoR	• Provide support to the SLIC for coordinating bi-monthly meetings • Set the agenda for discussion • Draft and circulate Minutes of Meeting • Any other support required by the SLEC or SLIC for carrying out their responsibilities

Source: Authors' compilation

7. ANNEXURES

Annexure I: Global Change Analysis Model (GCAM) Framework

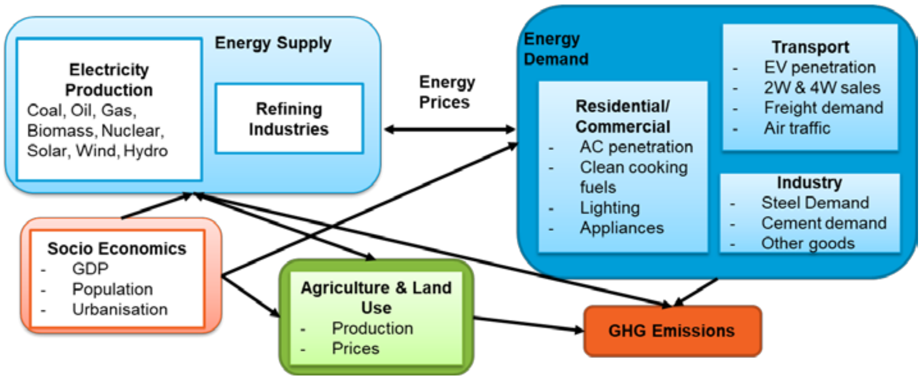
This Annexure presents the overall approach, assumptions, and the modelling framework utilised to model the long-term (2050) emissions pathway for Rajasthan while keeping the focus, wherever applicable until 2030, suited to this Roadmap.

The long-term modelling projections were conducted utilising the Global Change Analysis Model (GCAM). GCAM is an integrated assessment model used extensively for energy and climate policy analysis. The benefit of employing GCAM is its ability to project until 2100 and therefore allowing the exploration and implications of net-zero scenarios for India's 2070 target. GCAM's added advantage is the ability to choose between various energy fuels and technologies based on projected prices in the energy, water, agriculture and land use, climate and economy systems.

The Council on Energy, Environment and Water (CEEW) in collaboration with the Centre for Global Sustainability, University of Maryland, USA (CGS, UMD) developed the state-level version of GCAM-India which has a detailed representation of the energy system across 36 States and Union Territories. Energy demand is modelled for the households/buildings (urban and rural), transport, industry and agriculture sectors.

Energy demand from these sectors is serviced by the energy supply sector, including the power generation and refining industries. Figure A1 depicts the interaction between energy demand and supply and how it is modelled within GCAM.

Figure A1: Schematic representation of the Global Change Analysis Model (GCAM)



Source: Adapted from Joint Global Change Research Institute (JGCRI) and Pacific Northwest National Laboratory (PNNL)

The key drivers of future sectoral energy demands are economic and population growth, urbanisation rate, consumer behaviour, technology costs and energy prices, and government policies.

What GCAM does not do

- GCAM simulates the energy system's potential evolution based on assumptions about emissions limits, available technologies, efficiency, and costs, all of which carry high levels of uncertainty. Hence, modelling offers insights on policy directions that can help shape a transition pathway but cannot provide a definitive future view.
- GCAM prioritises minimising economic costs and doesn't address non-economic factors like equity or political feasibility.

Inputs and assumptions

This section captures all the key data inputs, sources and assumptions for designing future scenarios. It is important to note that the BAU scenario includes an inherently defined improvement in energy efficiencies and reduction in costs of technologies, while the NZ is a carbon constraint on the BAU, which follows India's ambition of reaching NZ emissions by 2070. For India to reach NZ by 2070, a peaking year for emissions is taken as 2040. **Notably, in the NZ scenario modelled in GCAM, all states collectively contribute to India's net-zero emissions goal by 2070, allowing an understanding of inter-state and inter-grid connections at the national level.**

Sources for historical data and future projections across socio-economic parameters and electricity supply and demand are given below.

Socio-economic data

- State-level population and urbanization projections are based on Census of India projections until 2036. Beyond that, similar growth trajectories are assumed to align the national numbers with United Nations (UN) population projections (National Commission on Population 2019).
- Gross Domestic Product (GDP) – Projection based on the theory of conditional economic convergence, meaning that less developed states will grow faster than the more developed ones and converge at similar income levels. National GDP projections are aligned with NITI Aayog projections. Table A1 below provides the assumed GDP growth rate of Rajasthan compared with the national trajectory.

Table A1: Assumed GDP growth rate of Rajasthan compared with India

	2015-20	2020-25	2025-30	2030-35	2035-40	2040-45	2045-50
Rajasthan	3.4%	8.1%	7.5%	7.0%	6.5%	5.5%	4.7%
India	3.5%	8.2%	7.7%	7.1%	6.5%	5.6%	4.7%

Electricity demand

Historical demand data is collected from:

- Buildings – Ownership of appliances from India Human Development Survey (IHDS) and National Survey Sample (NSS) for estimation of service wise demand in urban, rural and commercial buildings
- Transport - Zone-wise route kilometres from Ministry of Railways, vehicle registration data from Ministry of Road Transport and Highways (MoRTH); fuel consumption data from the GHG Platform India.
- Industry – Annual Survey of Industries (ASI) data

To estimate the future energy demands in the end-use sectors, GCAM utilises the following methodology.

Buildings: The future energy demand is influenced by three key factors:

1. The amount of floor space, which is determined by factors such as population, income, and satiation levels. Satiation levels indicate the marginal utility of the service beyond which it becomes negative, i.e., an increase in income does not lead to an increase in demand for the service.
2. The intensity of building service requirements per unit of floor space, which is influenced by climate, building shell conductivity, income, and satiation levels.
3. The energy sources and technologies chosen by consumers for their buildings.

Industry: Future energy demand in this sector is driven by population and income.

Transport: Future energy demand is dependent on per capita income, total price of the mode (includes for example, non-energy and energy costs, and value of travel time), population, and income and price elasticities.

Electricity supply

The model considers all sources of energy supply, including electricity and other fuels used across sectors. Here, we list out inputs, data sources, and assumptions for modelling the electricity supply.

- **Electricity generation** data from NITI Aayog Dashboard (NITI Aayog n.d.) and utility and captive electricity generation data at the state level from the CEA’s General Review 2021 (CEA 2021). Consumption data for all demand sectors is from the CEA Dashboard (CEA n.d.).
- **Costs of electricity generation** technologies trajectories are determined based on new investments and not current/historical trends in costs. Based on publications from Indian and international research institutions such as the Lawrence Berkeley National Laboratory (LBNL) (Abhyankar et al. 2021) and

CEEW (Chaturvedi et al. 2018), consultations with investors and various government agencies. The future cost trajectories until 2030 are captured in Table A2 below.

- **Transmission and distribution losses:** The model considers all-India transmission and distribution losses which improve over the years.

Table A2: Future cost assumptions for supply-side technologies in 2020 (INR/ kWh)

Costs of Technology	2020	2025	2030
Coal Super Critical	4.7	4.7	4.7
Solar PV	2.4	2.0	1.7
Wind	3.5	3.4	3.2
Nuclear	4.8	4.9	4.9
Gas (Domestic)	5.1	5.2	5.9
Gas (Imported)	8.4	8.5	9.7
Solar CSP	11.7	11.1	9.8
Integration Costs of Wind and Solar	**2020**	**2025**	**2030**
Solar	0.80	0.84	0.87
Wind	0.80	0.84	0.87

Annexure II: Assumptions on investment needs for Rajasthan's clean energy ambitions

Table A3: Technology cost assumptions until 2030 (in Constant 2020 INR crore/ MW)

Technology	2023	2025	2030
Coal	12.3	12.3	12.3
Nuclear	31.6	31.6	31.6
Hydro	12.7	12.7	12.7
Solar	5.2	3.3	3.0
Wind	8.0	7.9	7.7

Source: Author's compilation based on industry consultations and Chaturvedi and Malyan (2021)

Note: Currency conversion rate considered for 2020 at USD 1 = INR 82

Table A4: Annual storage requirement until 2030 (in GWh)

Financial year	Consumption (in BUs)	ESO (in %)	Annual energy storage (in GWh)	Annual energy storage with round-trip efficiency (in GWh)	Annual energy storage with depth of discharge (in GWh)
	(A)	(B)	(C) = (A)*(B)*1000	(D) = (C)/0.85	(E) = (D)/0.90
2023-24	90	1.0%	900	1,059	1,176
2024-25	96	1.5%	1,440	1,694	1,882
2023-25	103	2.0%	2,060	2,424	2,693
2024-26	110	2.5%	2,750	3,235	3,595
2023-26	117	3.0%	3,510	4,129	4,588
2024-27	124	3.5%	4,340	5,106	5,673
2023-27	133	4.0%	5,320	6,259	6,954

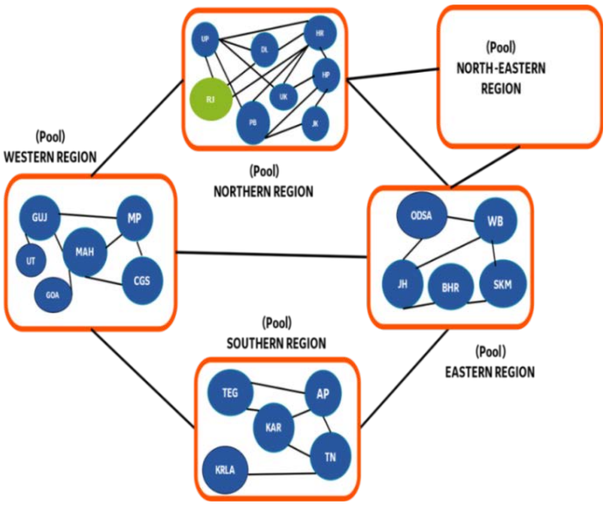
Source: Author's analysis based on CEA (2022a) and MoP (2022)

Note: Calculations based on assumed round trip efficiency of 0.85 and depth of discharge at 90 per cent.

Annexure IIIa: Modelling assumptions for Case 1

1. Model structure:

   GE Multi Area Production Simulation (MAPS) is a commercial, easy-to-use, Python-based linear optimisation tool.



   a. It is used to optimise the economic dispatch to assess the flexibility requirement while integrating 500 GW of non-fossil capacity in India.
   b. Each state is a node with a set of generators and a load.
   c. Power is free to flow from one node to another, subject to import and export transfer limits between regions and states.

2. System assumptions:
   a. Demand is projected based on the CEA 20th Electric Power Survey (EPS) with the base year as the calendar year 2022, i.e., January 2022 - December 2022.
   b. Dispatch at 15-minute granularity
   c. Operating reserves are modelled as five per cent of the load for each region
3. Cost assumptions:
   a. One per cent fuel cost escalation assumed for domestic and imported coal
   b. Projections from the Annual Energy Outlook are considered for projecting gas fuel price
   c. INR 40/kWh is considered a penalty for unserved energy.
4. Availability and operational constraints
   a. 9-15 per cent of planned and forced outages were considered based on the technology and capacity of the unit.
   b. MAPS consider fuel cost and heat rate to model the variable cost. Thus, real cost is considered at lower loading levels. The costs are benchmarked with data at the MERIT portal (MoP, n.d.) and daily coal reports by the National Power Portal (CEA n.d.).
   c. Ramp rates: One per cent per minute and three per cent per minute of rated capacity for coal- and gas-based power plants.

d. Minimum Technical loading (MTL) - 55 per cent of rated capacity for all coal-fired plants except for the units corresponding to 74 GW net capacity (40 per cent for those units)) and 40 per cent for closed-cycle gas turbine (CCGT) power plants.

e. The minimum downtime considered is eight and four hours for a coal-based and CCGT plant, respectively.

5. Other assumptions

a. CUF for upcoming solar and wind is considered 23 per cent and 30 per cent, respectively.

Annexure IIIb: Modelling assumptions for Case 2

1. Model structure:

a. GridPath is an open-source, easy-to-use, Python-based grid analytic tool.

b. It uses multi-integer optimisation modelling to model an economic dispatch

2. System assumptions:

a. Demand is projected based on the CEA 20th Electric Power Survey (EPS), with the base year as July 2021 - June 2022 (excluding the non-COVID-19 period).

b. Dispatch at 15-minute granularity

3. Capacity assumptions:

a. To meet the RPO targets, capacity addition for solar and wind is considered.

Table A5: RPO and CUF assumptions

Obligation	Description	Capacity in MW (CUF)
Wind RPO - 6.94 %	Met by generation from wind projects installed after 31 Mar 2022	New Wind - 5,147 (28%[73])
Others RPO - 33.57 %	Met by production from any RE project	Existing Solar - 4,336 (17%) Existing Wind - 4,111 (24%) New Solar - 16,063 (25%)

73 As per National Institute of Wind Energy (NIWE 2023), Rajasthan has a potential of 284 GW at 150m hub height, out of which, 230 GW lies between 25 to 30 per cent CUF.

b. Additional planned 2.4 GW coal, 100 MW hydro, and 700 MW nuclear is added along with 1.9 GW retirement of thermal capacity (CEA 2023f).

c. Short-term bundled contracts are not modelled to be there in 2030

d. 590 MW-7 hour planned contracts for pumped storage capacity are considered.

4. Cost assumptions:

   a. Two per cent fuel cost escalation is assumed for the conventional power generators, as per the RERC order.[74]

   b. INR 20/kWh is considered a penalty for unserved energy.

5. Availability and operational constraints

   a. Eight per cent and seven per cent planned maintenance and forced outages, respectively.

   b. Ramp rates - One per cent per minute and four per cent per minute of rated capacity for coal-based and gas-based power plants, respectively.

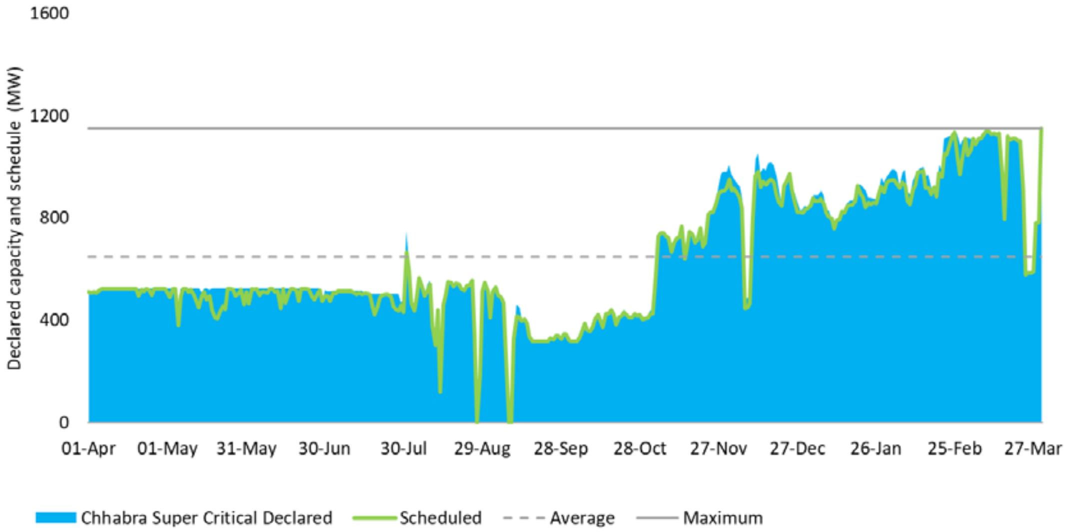
   c. Minimum Technical Load (MTL) - 55 per cent and 40 per cent for coal-fired and closed-cycle gas turbine power plants, respectively.

[74] Rajasthan Discoms' petition for approval of true-up of FY 2021-22 to RERC-Petition No. RERC 2066/2022, 2067/2022, 2068/2022

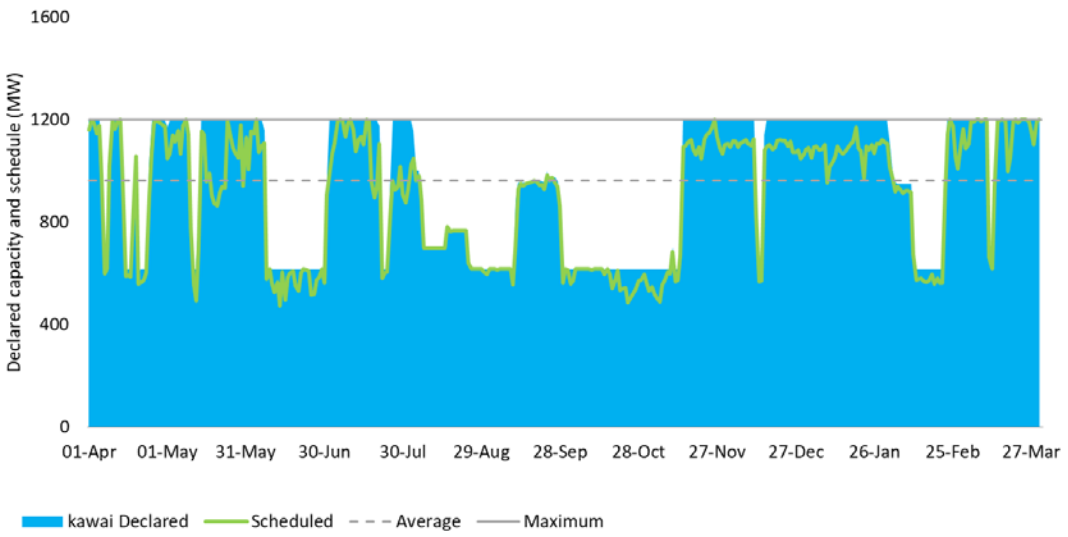
Annexure IV: Plant-wise daily average declared capacity vs. schedule for FY22

This Annexure illustrates plant-wise daily average declared capacity versus the scheduled energy for select thermal plants of Rajasthan. This analysis is based on the plant-wise data obtained from the SLDC for FY22.

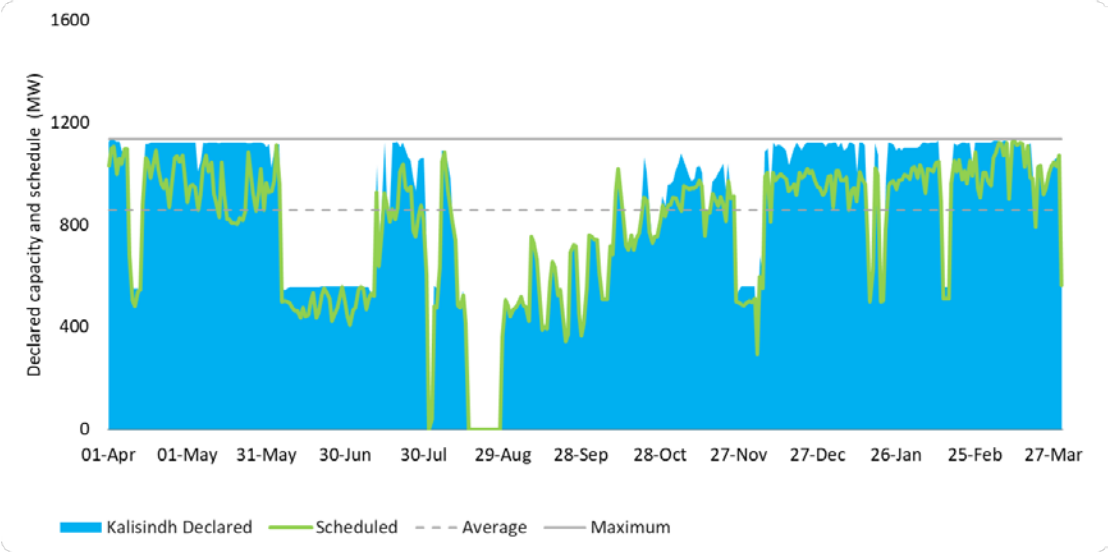
Chhabra Super Critical



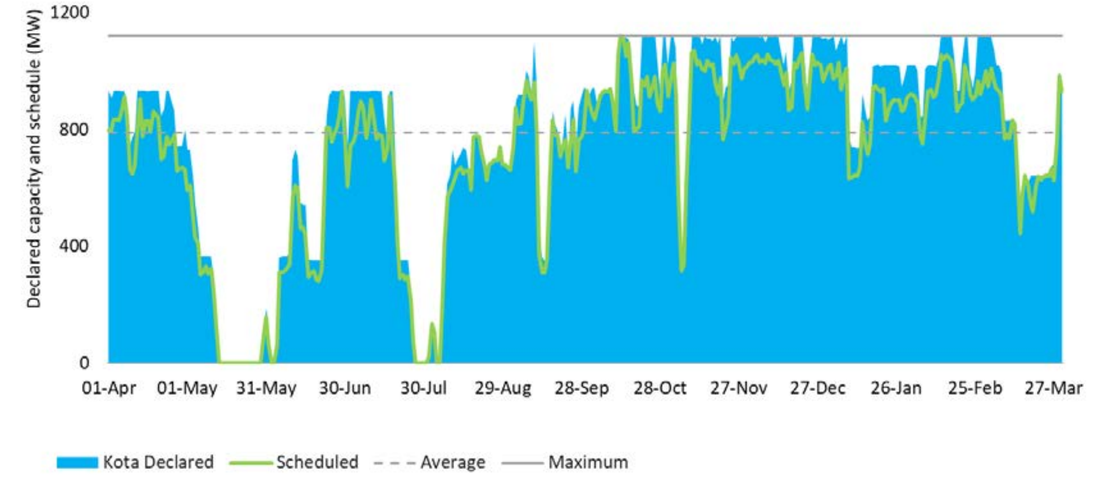
Kawai



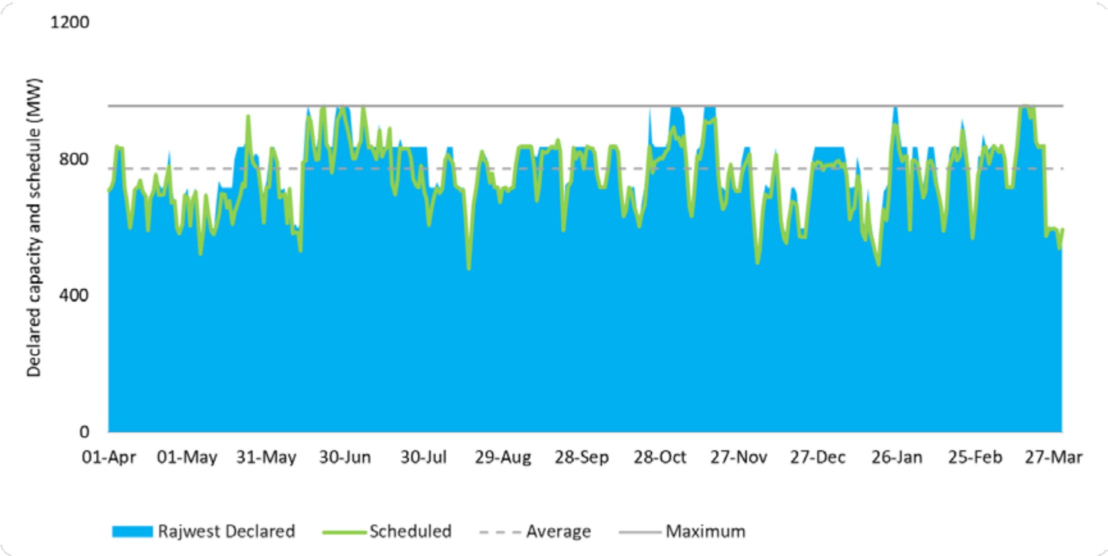
Kalisindh



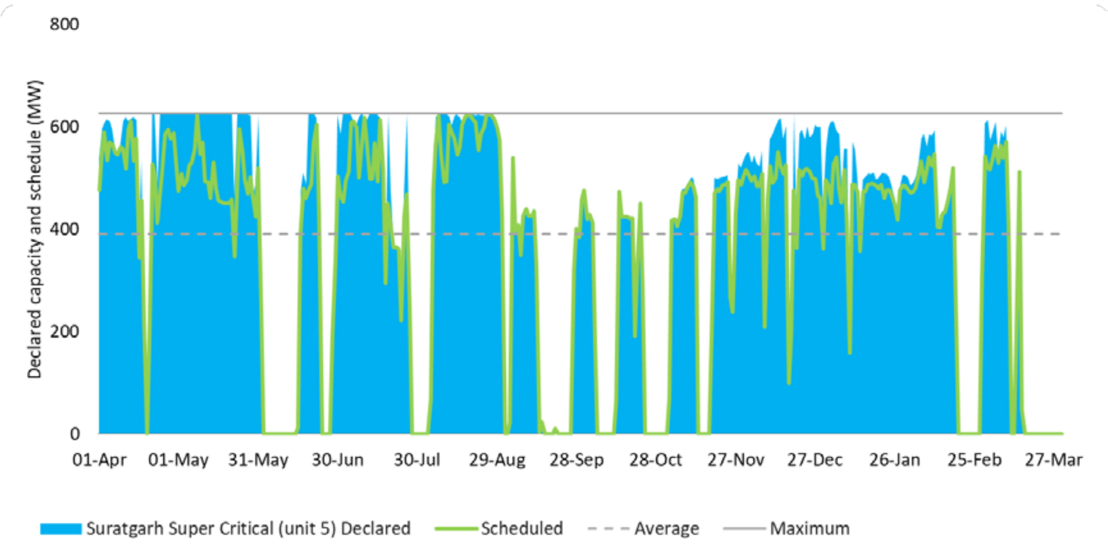
Kota



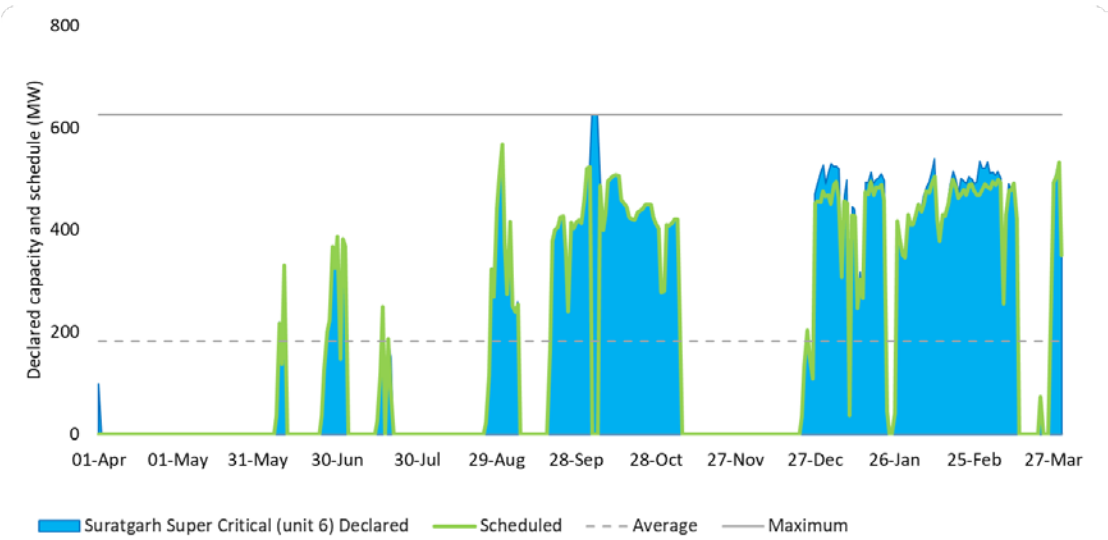
Rajwest



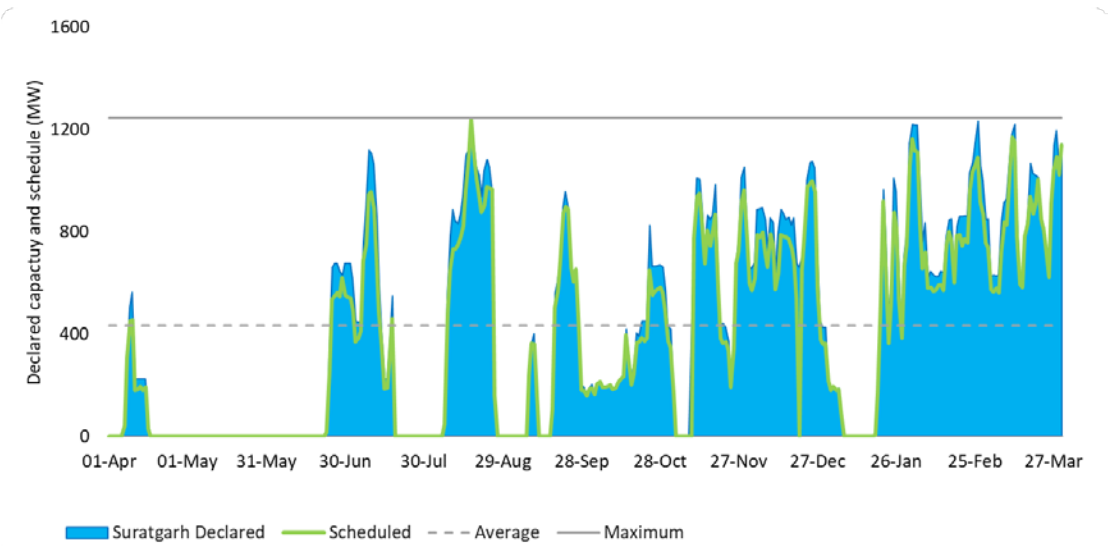
Suratgarh Super Critical unit-5



Suratgarh Super Critical unit-6



Suratgarh



Annexure V: Reasons for unavailability of Rajasthan's thermal power plants

Table A6 is a heat map indicating the number of times generating units were in outage due to a given reason in each month of FY22. We have further grouped the outage reasons as reported in CEA's operational monitoring reports into categories as follows:

1. **Boiler-related:** Water wall tube leakage, low/high drum-level, abnormal furnace draft, furnace flame failure, air preheater issues and other miscellaneous issues,
2. **Boiler auxiliary:** electrostatic precipitator (ESP)-related issues, auxiliary fan problems, and miscellaneous issues,
3. **Turbine-related issues:** Failure of turbine governing system, failure or misalignment of turbine bearing, high vibration, low vacuum, condenser, control valve, governing system, HP and LP bypass system, and miscellaneous issues,
4. **Generator issues**: Generator transformer problems, cooling system failure, earthing faults, DC supply failure, protection relay problems,
5. **Others:** Unit not yet commissioned, accident, strikes, and other miscellaneous issues.

Table A6: Count of reason-wise outages in each month of FY22 for selected power plants

Reason for outages/Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Boiler-related	8	3	9	10	13	14	7	11	11	7	7	18
Boiler auxiliary	2	1		3	3	5	5	7	7	3	4	9
Coal/fuel unavailability					9	8	6	4		1	1	2
Reserve Shut Down	7	8	12	16	15	13	2	7	4	8		3
Statutory outage (annual maintenance)	3	1	2	3	2	1	1	1				
Switchyard/electrical issues	2	1	2			2	2	1	3	1		2

Reason for outages/Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Turbine-related issues	2	1	3	2	5	2	1	3	2	3	3	5
Coal handling/Milling system				1	1	1	1		1		1	2
Generator-related	1		2	1	1	1	1	2	2	2		3
Others	1	2	2	3	2	2	3	1	1	1	1	3
Turbine auxiliary							1					1
Unit uneconomical	2	2	2						1			
Water unavailability	1	1	2	1								
Control system and protection/relay interlock problems				1			1					
Balance of Plant/air supply issue		1										
Ash handling system issues									1			
Grid voltage problems	1											

Source: Author's analysis based on data reported under CEA's daily outage report

Annexure VI: Suggested guidelines for MoD preparation

Table A7: Suggested guidelines for the methodology to prepare the MoD stack

S. No.	Purpose of guideline	Suggested guidelines
1.	Periodicity and date of preparation of MoD stack.	● Variable Charge (VC) of the immediately preceding month, and in case the VC of the immediately preceding month is not available, the average of the latest available VC for the preceding three months should be considered for preparation of the MoD stack. ● RUVNL to prepare the fortnightly MOD stack, and SLDC to upload by 12th and 27th day of every month. ● RUVNL/discoms to approach RERC on account of new source, revision in Variable Charges due to issuance of Tariff Order by CERC or RERC and impact of change in Law as per PPA.
2.	Guidelines for capacity declaration by generating units	● Apart from the day-ahead generation schedule, the generating company shall also provide additional information regarding fuel availability and unit-wise planned outages. ● In accordance with Section 54 of RERC MYT Regulations 2019, which specify the demonstration of declared capacity by power plants, SLDC should ask generating stations to demonstrate the maximum DC and Daily Capacity Index of the generating unit for the particular time block as well.
3.	Basis of preparation of the MoD stack, including the VC to be considered	● Discoms/RUVNL should submit data for VC of generating stations/units to SLDC. ● For power plants whose tariff is determined by the Commission under Section 62 of the Electricity Act, 2003, the VC for MoD purposes shall be the ECR plus the actual FSA. ● For centrally-owned power plants, the VC for MoD purposes shall be the landed cost at the state periphery. ● For PPAs entered under Section 63 of the Electricity Act, 2003, the VC for MoD purposes shall be the ECR plus the impact of change in law.
4.	Identification of must-run stations and guidelines for operating hydro stations (currently being used for agricultural purposes)	● The SLDC needs to ensure that the intended purpose of hydropower plants is not defeated. Moreover, where hydro plants are primarily operated for agricultural purposes, schedules for such plants need to be declared a week in advance for preparation of the MoD stack.
5.	Guidelines for operating	● MTL for coal /gas-fired/multi-fuel based thermal

S. No.	Purpose of guideline	Suggested guidelines
	the power plants (RSD, minimum technical load (MTL), etc.)	generating unit connected to the state transmission grid shall be 55 per cent of its installed capacity or as amended under the Indian Electricity Grid Code. ● Discoms should try to procure the highest possible capacity from the units permitted by the system rather than scheduling the units at MTL. ● The Reserve Shut Down (RSD) should be implemented for the capacity available in excess of the largest unit contracted by the discoms. ● The RSD should be applied to units with higher VC in the MoD stack, subject to grid conditions. ● Adequate Spinning Reserve for frequency stabilisation shall be maintained.

Source: Authors' analysis

Annexure VII: Details of pilots on improving demand forecasting accuracy

The Ministry of Power, Government of India organised the Powerthon 2022 under the Revamped Distribution Sector Scheme (RDSS), where it invited technology solution providers (TSPs) to build and test artificial intelligence (AI)/machine learning (ML)-based solutions to nine problem statements on key aspects of power distribution. Table A8 contains a brief on the solutions provided by TSPs on the problem statement on enhancing demand forecasting using AI/ML-based solutions (REC et al. 2022).

Table A8: Briefs on pilot projects using advanced methods for day-ahead forecasting

TSP	Pilot Brief	Outcome/Benefits
Esyasoft Technologies Private Limited	Developed 15-minute interval load forecast models based on statistical and deep learning models by considering the weather, holidays, and social/religious events and time block-wise demand. **Discom:** Madhya Pradesh Paschim Kshetra Vidyut Vitaran Company Limited	The pilot is expected to achieve day-ahead forecast accuracy of at least 97.5 per cent.
50 Hertz Limited	AI/ML-based load and RE forecast to minimize demand-supply gaps and provide complete portfolio management solutions, including mechanisms to augment the discom's daily operational requirements. **Discom:** Punjab State Power Corporation Limited	The forecasting system is integrated with the discom's SCADA system, and the day-ahead forecast accuracy has been improved by one per cent over PSPCL's existing method.
EMA Solutions Private Limited	Custom model development using an ensemble approach, a combination of models considering the weather, agricultural patterns, holidays/special events, outages, diverse demographics, geography, demand mix, and climatic variations across states, and using load centre-wise demand data of 2017-22. **Discom:** Tamil Nadu Generation and Distribution Corporation	Higher accuracy on day-ahead/same-day demand forecasting with the error below the benchmark to aid the discom in planning, trading, Deviation Settlement Mechanism management and procurement cost reduction.
SCOPE T&M Private Limited	R statistical programming and Extreme Gradient Boosting machine learning package to	Method expected to improve daily forecast accuracy compared to discom's statistical method by

TSP	Pilot Brief	Outcome/Benefits
	forecast demand and build on historical 5-year actual demand data; Feature Engineering on maintenance schedules, consumer profiles, consumer counts, and holidays; GIS to use weather data as an input for the model. **Discom:** Telangana State Northern Power Distribution Company Limited	reducing Mean Absolute Percentage Error (MAPE) by 50 per cent; MAPE improvement of up to 7.5 per cent for weekly, 12 per cent for monthly, and 14 per cent for yearly forecasts.
REConnect Energy Solutions Private Limited	The solution uses a customised configuration of Numerical Weather Prediction models incorporating weather data for weekly and daily forecasts; the method consists of weather sensitivity analysis data-based pattern recognition based on circle-wise data. **Discom:** Uttar Haryana Bijli Vitran Nigam	• Accurate and automated intra-day, day-ahead, week-ahead, month-ahead load forecasts • Improved power procurement planning

Source: Authors' compilation based on REC et al. (2022)

Annexure VIII: The impact of per unit regulatory surcharge on consumers

Tables A9 and A10 illustrate the impact of a per-unit regulatory surcharge on consumers with different consumption levels.

Table A9: Annual recovery of unfunded revenue gap of ~INR 9 crore, through a 12.8 per cent regulatory surcharge, imposes a burden of ~INR 2.6 crore on category-1 (low consumption) consumers

Particulars	ID	Unit	Amount
Sales to consumer category-1	A	MUs	100
Sales to consumer category-2	B	MUs	160
Total discom sales	C=A+B	MUs	260
Tariff for first 100 MUs	D	INR/kWh	2
Tariff for remaining MUs	E	INR/kWh	5
Total revenue from sales to category-1	F=A*D	INR crore	20
Total revenue from sales to category-2	G=(A*D)+(B-A)*E	INR crore	51
***Ad valorem* regulatory surcharge**	H	Percentage	12.80%
Surcharge recovered from category-1	I=F*H	INR crore	2.6
Surcharge recovered from category-2	J=G*H	INR crore	6.6
Total surcharge recovered	K	INR crore	9.1

Table A10: Annual recovery of unfunded revenue gap of ~INR 9 crore (as above), through a per unit regulatory surcharge of INR 0.35/ kWh, imposes a burden of INR 3.5 crore on category-1 (low consumption) consumers

Particulars	ID	Unit	Amount
Sales to consumer category-1	A	MUs	100
Sales to consumer category-2	B	MUs	160
Total discom sales	C=A+B	MUs	260
Tariff for first 100 MUs	D	INR/kWh	2
Tariff for remaining MUs	E	INR/kWh	5
Total revenue from sales to category-1	F=A*D	INR crore	20
Total revenue from sales to category-2	G=(A*D)+(B-A)*E	INR crore	51
Per unit regulatory surcharge	H	INR/kWh	0.35
Surcharge recovered from category-1	I	INR crore	3.5
Surcharge recovered from category-2	J	INR crore	5.6
Total surcharge recovered	K	INR crore	9.1

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